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IRON AND STEEL

IRON AND STEEL

THEIR SOURCES, VARIETIES, PROPERTIES, AND MANUFACTURE

WITH NUMEROUS ENGRAVINGS AND DIAGRAMS

BY

WILLIAM HENRY GREENWOOD

F.C.S., M.INST.C.E., M.I.M.E. ASSOCIATE OF THE ROYAL SCHOOL OF MINES

REVISED AND REWRITTEN

BY

A. HUMBOLDT SEXTON

F.I.C., F.C.S.

PROFESSOR OF METALLURGY IN THE GLASGOW AND WEST OF SCOTLAND TECHNICAL COLLEGE

CASSELL AND COMPANY, LIMITED

LONDON, PARIS, NEW YORK, TORONTO & MELBOURNE

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PREFACE.

IRON : ITS SOURCES, PROPERTIES, AND MANUFACTURE contains, in a form convenient for everyday use, a comprehensive treatise on the subject. The contents of this manual are based on the highly esteemed book written by the late William Henry Greenwood.

Without omitting any essential part of the original work the matter has been revised, partly rewritten, and brought up to date by Mr. A. Humboldt Sexton, F.I.C., F.C.S., Professor of Metallurgy in the Glasgow Technical College. Needless to say, many changes have taken place since the previous edition was published, and whilst descriptions of new processes and appliances have been given, those of the older methods which are still in vogue in many works have been retained and revised. In this manner the manual has been made valuable, not only to the student but to all employed in iron works.

Readers who may desire additional information respecting special details of the matters dealt with in this book, or instructions on any kindred subjects, should address a question to the Editor of WORK, La Belle Sauvage, E.C., so that it may be answered in the columns of that journal.

<div align="right">P. N. HASLUCK.</div>

La Belle Sauvage, London,
July, 1907.

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LIST OF ILLUSTRATIONS.

IRON: ITS SOURCES, PROPERTIES, AND MANUFACTURE.

INTRODUCTION; TERMS EXPLAINED.

IRON in a chemically pure state exists only as a curiosity, and has no practical application in the arts. It has no value as a constructive material, and cannot be prepared upon a large scale. Iron in combination with small proportions of carbon and other elementary bodies, as sulphur, silicon, phosphorus, etc., yields the various commercial forms of iron which are known as steel, malleable- or wrought-iron, and cast- or pig-iron, and these metals are by far the most important known.

The forms in which iron comes into the market are so many and so varied that it is very difficult to draw up satisfactory definitions. In general, the metal is called either iron or steel, the classification depending partly on chemical composition and partly on method of manufacture.

In this manual it is intended to deal with the varieties commercially known as iron, leaving the consideration of steel to a companion manual. The forms known as iron have been much longer in use than those known as steel, and are much more easy to define accurately—accurately, that is, from a technical rather than from a purely scientific standpoint.

There are two familiar forms of iron, very different in their character.

(1) **Malleable- or Wrought-Iron.**—This is undoubtedly the form in which iron was first used in the arts. It is still largely used, but is being gradually displaced for most purposes by mild steel, which, in many of its forms, it very closely resembles. It is comparatively pure, containing about

99·5 per cent. or thereabouts of pure iron, a small quantity of carbon up to ·2 per cent. or thereabouts, a small quantity of silicon—say ·1 per cent., and small quantities of other impurities. It is very malleable and ductile—that is, it can be rolled into sheet, or drawn into wire, either hot or cold—and when heated to bright redness it becomes so soft that it can be hammered or wrought into any required form, whence its common name. It is usually regarded as being the purest form of iron in commerce, but mild steels are now made of a higher degree of purity. It cannot be melted in an ordinary fire fed with solid fuel, and articles of it are always prepared by hammering, rolling, stamping, spinning, or similar processes, portions being united either by welding at a red heat or by a mechanical connection such as riveting.

(2) **Cast-iron or Pig-iron.**—This is the most impure form of iron, containing large quantities of various foreign constituents, some of which, however, can hardly be called impurities, since the metal would not be cast-iron if they were absent. The amount of iron present varies considerably, but usually is about 92 to 93 per cent. Carbon is always present, usually about 3·5 per cent., though it may reach 4·5, and silicon may range from about ·5 per cent. (in rare cases) up to 3·5 per cent. or even higher. Cast-iron may, indeed, be defined as being iron containing over 2 per cent. of carbon and some silicon, these being the essential constituents; whilst the other elements —sulphur, phosphorus, manganese, etc.—though almost always present may be regarded as being accidental constituents or impurities, because the absence of them would not prevent the metal being cast-iron. Cast-iron is prepared in a liquid condition, and as it flows from the furnace is usually cast into pigs, and is therefore called pig-iron. It is converted into the forms which may be required by melting and casting in moulds, of sand or other material, and therefore it is often called cast-iron.

Either one of these two forms of iron may be prepared directly from the ore or one from the other. In the very early days malleable iron was prepared directly, and cast-iron was unknown, but now cast-iron is always prepared directly from the ore, and malleable-iron is prepared from cast. In this manual, therefore, the preparation of cast- or pig-iron will be first described and explained.

Scope of this Manual.—Such metals as iron and steel may be studied from so many standpoints that it may be as well to indicate briefly the scope of this manual. It is intended to deal with the metals from the metallurgical standpoint only. That is, to describe the sources of the metals in nature and the methods by which the metal is obtained from these sources and prepared for subsequent use. Chemical subjects will have to be considered, but they will be dealt with only so far as they bear on the metallurgy of the metals. The properties of the metals will, of course, be discussed; but these will be considered mainly from the standpoint of the influence of impurities, of methods of manufacture and of treatment of the metal, not so much from the engineer's standpoint, as the use for which the metal is intended.

Technical Terms.—It is impossible to write a technical book without the use of technical terms, and brief explanations of a few of the terms that will be used are given below. These are only intended as a guide to the student who is quite new to the subject, and most of them will be discussed more fully in the text as occasion arises.

Annealing, in the case of iron and steel, is the term applied to the operation by which the metal is heated to bright redness, and then allowed to cool down slowly, either in the open air, or, more usually, under a layer of ashes or other bad conductor of heat. Annealing often corrects or prevents the irregularities in strength arising from unequal or irregular cooling in castings and forgings, and removes the hardening effect of work. The term annealing is also used for the long heating which is given to castings in the preparation of malleable cast-iron, and also to the operation of slowly heating crucibles to redness before introducing them into the steel melting furnace.

Calcination is the process in which iron-ores are heated in heaps, or kilns, at a comparatively low temperature, for the expulsion of water, carbon dioxide (CO_2), sulphur, and other volatile matters, with the oxidation of the ferrous oxide and carbonate to the condition of ferric oxide. The necessary heat is produced either by the combustion of the bituminous matters in the ore itself, as in certain Scotch blackband ironstones, by the combustion of sulphur in highly

sulphurous ores of copper and other metals, or by the addition of fuel which is mixed with the ore to be calcined in the heaps or kilns.

Cementation is a process in which a metal is made to take up a solid element, by being heated with it. In the metallurgy of iron the principal example is the carburising of malleable-iron, and the production of steel, by the prolonged exposure of the iron at a temperature below fusion, to the action of solid carbon. A similar action may go on in the blast furnace where the freshly reduced iron is in contact with the carbon of the fuel.

Cold-short expresses a condition of iron or other metal in which when it is worked by hammering or rolling at or below a dull red-heat the edges crack or fracture according to the degree of the cold-shortness; perhaps such metal may be worked with the utmost facility at a higher temperature. Small quantities of phosphorus, silicon, arsenic, and antimony induce cold-shortness in iron or steel, phosphorus being the most common cause of this defect.

Red-short is a term applied to metals which cannot be readily worked at a temperature at or above redness, although frequently such metal can be worked by hammering or rolling at ordinary temperature without fracture. Red-shortness is often the result of the presence of an undue proportion of sulphur in the metal, but copper, antimony, silver, calcium, etc., also produce the same effect.

Malleability is the quality of permanently extending in all directions, without rupture, by pressure, as by hammering or rolling, and is an essential quality of metal that is to be rolled into sheets. Russian sheet-iron has been reduced to a thickness not exceeding 770 to the inch.

Ductility is the property of being permanently extended by a tensile force, or drawn into wire. It depends partly on the malleability and partly on the tenacity of the metal. All malleable metals are more or less ductile. It is greatly influenced by the presence of impurities in the metals, and also varies with the temperature.

Elasticity.—When a substance is subjected to stress, it undergoes a change in form and perhaps in size also. For example, a bar subjected to a pulling stress will become longer. It is obvious that the force with which the bar

resists extension is the same as the force which is applied to produce the extension, and this is the measure of the elasticity of the body. The greater the force with which the body tends to return to its original form—that is, the greater the force needed to produce the extension—the greater is the elasticity of the substance.

If a bar of iron of 1 sq. in. in section be taken and a force of 1 ton be applied he bar will be stretched by a definite fraction of its own length. If the force be doubled the extension will be doubled, and so on, the extension being proportional to the extending force, or, as it is usually put, the strain is proportional to the stress. The modulus of elasticity, or Young's modulus, is the force that would be required to double the length of the bar provided the law of proportionality of stress and strain held good and the bar did not break. This condition can never be attained, but the modulus can be calculated from the ratio of strain to stress at lower pressures. The modulus of elasticity is the recognised measure of the elasticity of a substance.

If to the bar, of say 1 sq. in. in section, a stress of 1 ton be applied, the bar will elongate ; if 2 tons, it will elongate by double the amount, and so on as already explained. Also, if the stress of 1 ton be removed, the bar will return to its original length, so also if the 2 tons be removed, and so on ; but as the stretching force is increased a point is reached when the stretching ceases to be proportional to the force applied, and when, if the stretching force is removed, the bar does not return exactly to its original length, but has taken a permanent set. This is the limit of elasticity. The two factors, the Modulus of Elasticity and the Limit of Elasticity, are of the utmost importance in determining the utility of metals for structural purposes.

In the preceding paragraphs the elasticity has been considered only in the case of a stress in tension tending to lengthen the bar, but exactly the same laws hold good in the case of stresses producing compression or any other form of distortion.

Tenacity is the property of resisting fracture from the application of a tensile or stretching force, and is usually stated in England in terms of the number of tons or hundredweights required to break a bar of 1 sq. in. sectional area.

Figs. 1 to 6 show the common forms of test pieces. Figs. 7 to 11 show the forms of standard tensile test pieces as proscribed by the Engineering Standards Committee.

In France, Germany, and generally over the Continent, the force or weight is expressed in kilogrammes (2·2046 lb.) with the square centimetre as the unit of area (the square centimetre = 0·15500591 sq. in.). Tons per sq. in. × ·00635 =

Fig. 1.—Cylindrical Test Piece   Fig. 2.—Fractured Test Piece
        with Screwed Ends.   with Screwed Ends.

Fig. 3.—Cylindrical Test Piece with Button Ends.

Fig. 4.—Fractured Test Piece with Button Ends.

Fig. 5.—Bar Test Piece.

Fig. 6.—Fractured Bar Test Piece.

kilogrammes per square centimetre (kg. per cm.). The tensile strength of a metal depends on its composition and also on the treatment to which it has been subjected. It is easily measured, and therefore is taken as one of the standards in the specification of metals.

Extension.—When a bar is subjected to tensile stress it extends very considerably before fracture, so that the piece when the broken edges are put together, is longer than the

original piece. The increase in length is the extension or elongation. As it does not take place equally over the whole length of the test piece, the length of the test piece used must
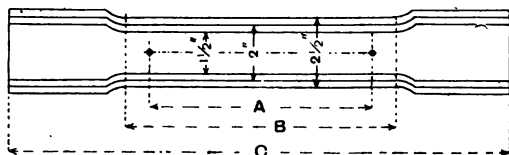
Fig. 7.—Test Piece for Plates (Standard Form): A, gauge, length 8 in.; B, parallel for not less than 9 in.; C, total length above 18 in.
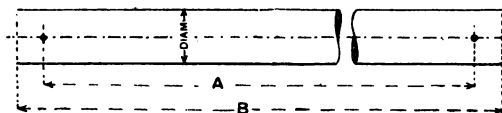
Fig. 8.—Test Piece for Bars, etc. (Standard Form): A, parallel for not less than 8 times the diameter; B, enlarged ends parallel for not less than 9 times the diameter.
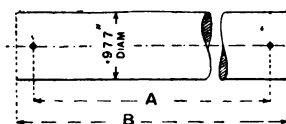
Fig. 9.—Test Piece for Forgings, Castings, etc. (Standard Form): A, gauge, length 3½ in.; B, parallel for not less than 4 in.
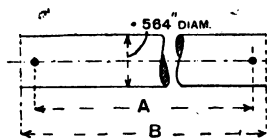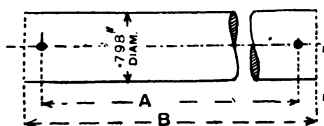
Figs. 10 and 11.—Test Pieces for Tyres, Axles, Forgings, Castings, etc.

always be stated. It is usually 8 in. or 10 in. for testing iron or steel.

Fatigue is the diminished resistance to fracture which comes after repeated applications of stress, especially after stresses varying within a wide range.

Fining is an old term, still used in some districts, and usually describes a process of purification by oxidation.

Softness is a relative term sometimes used to express the quality of a metal whereby it easily permanently yields to pressure without fracture.

Toughness, in metals, is a relative expression of the power of resisting fracture by bending or torsion. It is measured by the number of times to which a definite section of the metal can be bent through a certain angle on either side from the perpendicular without any fracture.

Flow of Metals.—When metals are subjected to great stress they pass into a condition in which the molecules can flow freely one over the other, and therefore in which the metal behaves for the moment almost as if it were a liquid. All metal rolling, stamping, and similar processes depend on this property. Some metals, as lead and some alloys, flow so readily that they can be made into tubes or other forms by extrusion through dies. Malleability and ductility are due to this flow of the metal.

Welding is the quality whereby two clean surfaces, brought together at a suitable temperature, under pressure will unite to form one coherent mass. The surfaces must be perfectly clean, and the metals must be at a temperature high enough to produce a plastic state in which there is considerable molecular freedom. This property of welding is typically shown by wrought-iron at a white heat, and by the milder qualities of steel at a red or white heat. It is essential that the surfaces be free from oxide, and to obtain this with iron a quantity of sand (silica) is thrown on the surfaces; this forms with the oxide of iron a readily fusible and fluid slag on the welding surface, and the subsequent pressure forces this out, leaving the metallic surfaces in contact, clean and free from oxide. For steel the smith often prefers a mixture of 10 parts of borax ($Na_2B_4O_7$) and 1 of sal-ammoniac (NH_4Cl) to 1 of sand. In order that two metals should weld well it is essential that the point of maximum molecular freedom in each should be at about the same temperature.

Ore is the metalliferous material extracted from the mine, and to be considered as an ore it must contain enough of the metal to pay for extraction. The ores of iron are

oxides or carbonates of the metal, accompanied by certain extraneous matters, gangue, or vein stuff, essentially siliceous, calcareous, argillaceous, or bituminous in character. In Wales and some other districts the term " mine " is used as synonymous with ore.

Smelting is the separation or extraction of a metal from its ores on a large scale. When the ore is an oxide the process is one of reduction. The active element used in effecting the reduction is known as the " reducing agent," and in the case of iron this is invariably carbon or carbon-monoxide (CO), always at a high temperature.

Flux is a substance added to the furnace charge, which, by combining with the siliceous and other extraneous matters or gangue of the ore, yields at the furnace temperature a readily fusible substance known as a slag. Iron ores having a gangue of infusible quartz might be smelted without the addition of flux, but this would cause a loss of iron, since ferrous oxide (FeO) readily combines with quartz or silica, producing a fusible ferrous silicate, which is not reducible by carbon or carbonic oxide, the reducing agents of the blast furnace, and which therefore would pass away into the slag with a corresponding loss of iron. A similar result follows if the gangue be argillaceous, for the aluminous silicate (clay), which alone is practically infusible, combines readily with a portion of the ferrous oxide of the ore, producing thereby a double silicate of alumina and iron, which is easily fusible ; but to obviate the loss of iron which would thus result it is usual to add a flux of limestone, the lime of which enters into combination with the silica or siliceous clay, yielding fusible silicates, or slags of the double silicates of lime and alumina. When the ores are the rich oxides of iron (hæmatites), lime and also argillaceous matters, in the form of shales or argillaceous iron-ore, are often added.

Slags are the earthy portion of the ores combined, when necessary, with fluxes so as to produce a fusible mass which can be tapped from the furnace in a liquid condition.

A slag must be fusible at the temperature of the furnace, so that it can be tapped out, and must be of sufficiently low specific gravity, and sufficiently liquid, to allow the metal to separate readily, and it should be as free as possible from the metal being smelted. Slags are almost invariably silicates :

B

in iron smelting, silicates of lime and alumina; and in lead and copper smelting, and in the preparation of malleable iron by puddling, silicates of iron.

Slags always form an important part of the by-products of any metallurgical industry, and the profitable disposal of them is an important part of the economies of the works. The character of slags produced in the various branches of the iron industry, and the use that can be made of them, will be discussed later.

Puddling is a process by which pig-iron or refined iron is converted into malleable iron in fixed reverberatory furnaces. The term pig-boiling is sometimes applied to the process of puddling as now carried out.

Refining is the process sometimes employed to effect the partial purification of pig-iron by the removal of silicon, so converting it into white, refined, or plate metal. This is a preliminary to its conversion into malleable iron by treatment in the puddling furnace or charcoal finery.

Shingling, or **nobbling,** is the treatment received by the puddled ball under the hammer, for the welding together of its particles into a solid bloom, and the expulsion of slag and oxides from the puddled ball.

Temperatures employed in working iron and steel are often expressed by such terms as "red-heat," "white-heat," etc., and the following figures indicate approximately the temperatures so defined :—

Incipient redness	about	525° C.	(977° F.).
Dull red	,,	700° C.	(1292° F.).
Cherry red	,,	900° C.	(1652° F.).
Deep orange	,,	1100° C.	(2012° F.).
White-heat	,,	1300° C.	(2372° F.).
Dazzling white	,,	1500° C.	(2732° F.).
		to 1600° C.	(2912° F.).

CHAPTER II.

REFRACTORY materials are used in the metallurgical treatment of iron and steel for the building and lining of furnaces, for the preparation of crucibles, and other minor purposes. Those most used are fire-clays, refractory sands, fire stones (refractory rocks), lime, magnesian lime, graphite, etc. The most generally used material is clay, which is the basis of nearly all the firebricks used, and of all the crucibles.

Clay is essentially a hydrated silicate of alumina, the purest form, Kaolin, having the formula $Al_2O_3,2SiO_2,2H_2O$. The most important property of clay is its plasticity. That is, when mixed with water, in addition to that which it contains in combination, the mass becomes so plastic that it can be moulded to any required form. On drying, the mass acquires some firmness, and on heating to redness the water of combination is expelled, the mass becomes hard, and is no longer capable of being made plastic by the addition of water. The combined water has been expelled.

All natural clays contain other materials intermixed with the clay, and when these are of such a character as not to seriously impair its power of resisting a high temperature it is called a fire-clay.

Pure kaolin contains 46·4 per cent. of silica ; it is very infusible, but cannot be used for making fire-bricks. The fire-clays tabulated on the next page—and it is true also of almost all others—contain a large excess of silica over and above that present in the clay.

The value of a fire-clay largely depends upon its freedom from such bodies as lime, magnesia, ferrous oxide, and particularly the alkalies, any of which at high temperatures would readily combine with the free silica (SiO_2) of the clay, with the formation of readily fusible silicates. The presence of 3 to 4 per cent. of foreign basic oxides in

an ordinary clay—that is, one that contains much free silica —will render it fusible; but the more aluminous the clay the larger is the allowable quantity of bases.

The following analyses of well-known fire-clays will give an idea of their composition :—

ANALYSES OF FIRE-CLAYS.

	A	B	C	D
Silica	63·30	67·12	66·10	44·37
Alumina	23·30	21·18	19·80	38·59
Potash	—	2·02	—	—
Soda	—	—	—	—
Lime	·73	·32	—	·51
Magnesia	—	·84	—	·30
Ferrous Oxide (FeO) . .	1·80	—	—	1·82
Ferric Oxide (Fe₂O₃) . .	—	1·85	6·30	—
Water Combined . .	—	4·82	—	
„ Hygroscopic . .	10·30	1·39	7·50	14·47
Organic Matter . . .	—	·90	—	
	99·43	100·44	99·70	100·00

A.—Stourbridge Clay.   B.—South Wales Clay.   C.—Continental Clay used for Fire-bricks.   D.—Garnkirk Clay.

Ferric oxide, if present in large quantity, imparts a reddish colour to the burnt clay. It does not much reduce the refractoriness of the clay, provided it is only used in an oxidising atmosphere, as ferric oxide and silica do not combine; but heated in a reducing atmosphere, it is reduced to ferrous oxide, which readily combines with silica. Iron pyrites is usually present in tiny particles distributed through the mass of clay. During firing the sulphur is burnt out and ferrous oxide is formed. This combines with the silica, forming black ferrous silicate, which sinks into the porous clay, and a tiny hole is left where the pyrites was, surrounded by a black stain of ferrous silicate.

Fire-clays occur largely in the coal measures of the carboniferous strata, also in various other geological formations. Most of those used in the manufacture of fire-bricks belong to the carboniferous period. Clays obtained from the same locality and apparently of the same kind are found to differ widely in their degree of fusibility, this to a large extent arising from variations in the proportions of silica.

If a material will readily combine with a basic oxide at a high temperature it is said to be an acid material, silica being the acid substance almost invariably present; on the other hand, if it will combine readily with siliceous materials it is said to be basic, whilst if it can be heated either with silica or with a basic oxide without fusion it is said to be neutral. The large quantity of silica in all ordinary fire-clays shows them to be distinctly acid bodies, in the sense defined above. Much more acid materials are often used.

Ganister is a siliceous rock containing just enough clay to bind the mass together. Dinas rock or Dinas clay is a siliceous rock of no binding power, containing often as much as 98 per cent. of silica, and even more siliceous materials are sometimes used, as, for instance, calcined flints, which are used in the manufacture of some silica bricks, and fine white sand, which is nearly pure silica.

Rocks, etc.—Fire stones, very refractory sandstones, are sometimes used in furnace construction. They are hard and difficult to work, and therefore costly; but they yield the most durable bottoms for the blast furnace, and therefore are still largely used for that purpose. Rocks can never be used in places subject to sudden fluctuations in temperature.

Fire-bricks.—Clay is almost invariably made into fire-bricks; these should withstand continued exposure to the highest temperatures of a furnace without decomposition, cracking, fusing, or sensibly softening; they should bear considerable pressure whilst heated without suffering fracture or distortion; they should be unaffected by considerable, and sometimes sudden, variations of temperature. For certain purposes they require to be unaffected by contact at a white heat with such metallic oxides as those of iron and magnesia, or other basic slags or scoriæ; contact with heated fuel should be without effect upon them; they should be able to resist at one time an oxidising, and at another a reducing, action. For convenience in building fire-bricks are required to be regular in shape and uniform in quality.

All these qualities are never to be found to perfection in one brick; and in each case the best possible compromise has to be made. For blast-furnace construction, bricks such as the Glenboig, which have not a very large excess of silica present, are the most suitable, and highly siliceous bricks are

to be avoided, as the slags contain a considerable quantity of lime. In the upper part of the blast furnace, where the temperature is not very high, highly refractory bricks are not by any means necessary.

In the manufacture of fire-bricks, their constituent fire-clays cannot be used directly as they are found—that is, in the raw state—since, although the clay may be sufficiently refractory for the purpose intended, yet it is not sufficiently uniform in composition, and if used alone the brick would shrink far too much.

The clay is sometimes tempered by exposure to the air, protected from rain, for some time, and is then crushed in a suitable mill to a coarse powder. Any necessary addition to prevent shrinkage is then made. The usual substance added is burnt clay in the form of old bricks, but cinders, graphite, sand, or other materials may be used. Whatever the material is, it is crushed to the same degree of fineness as the clay, and the materials are then mixed with water and thoroughly incorporated in a pug-mill; and moulded into bricks by machine or hand labour, as in the case of ordinary bricks. The bricks are then laid out to dry, and, when sufficiently dry and resisting, are placed in kilns, each holding from 15,000 to 20,000, arranged so as to allow of the heated gases from the combustion of the fuel burning on a grate at the end of the kiln to circulate around and between them. After some six days' exposure to heat in this manner, the bricks are sufficiently burnt and ready for withdrawal, for which purpose the fires are drawn, and the kilns allowed to cool down. Gas fired kilns are now largely used for brick burning. The shrinkage during the drying and burning of fire-bricks is considerable, so that for the production of a 9-in. brick the raw clay brick will require to be from $\frac{1}{2}$ in. to $\frac{3}{4}$ in. longer than the burnt brick; the exact amount requires to be determined for each mixture of clay, since the amount of contraction varies for almost every clay or mixture of clays.

Fire-bricks must be set in fire-clay and never in lime mortar, otherwise at furnace temperatures the free silica of the brick will combine with the lime of the mortar, and produce a readily fusible silicate of lime, with consequent destruction of the furnace.

Silica bricks are made much in the same way, but the

crushed siliceous material is mixed with a small quantity (about 1 per cent.) of lime, which combines with some of the silica and forms a silicate which frits the whole together. Such bricks are never strong.

ANALYSES OF FIRE-BRICKS, SILICA BRICKS, GANISTER.

	A	B	C	D	E
Silica . .	62·10	58·00	97·5	92·0	96·7
Alumina . .	33·10	36·50	1·4	5·0 ⎫	1·3
Ferric Oxide .	3·00	1·67	0·55	2·5 ⎭	
Lime . .	0·90	0·50	0·15	0·3	2·0
Magnesia . .	trace	0·90	0·10	0·2	—
Potash . .	0·90	2·12	—	—	—
Soda . .	—	0·30	—	—	—
	100·00	99·99	99·70	100·0	100·0

A.—Glenboig Fire-brick. B.—Newcastle Fire-brick. C.—Dowlais Silica Brick. D.—Sheffield Ganister Brick. E.—Silica Brick.

Siliceous sand is an exceedingly refractory material, containing in some varieties as much as 97 per cent. of silica, the remainder consisting of a little lime, alumina, oxides of iron and water. This sand is used for mixing with fire-clays, etc., in the manufacture of fire-bricks, also as the principal ingredient in the mortar used in the setting of silica bricks; it is also employed in making the bottom or hearth of the Siemens melting furnace. Sands less pure than the above, containing enough clay to give binding power, are also employed for making the pig-beds of blast furnaces, and more plastic sands for making moulds for casting iron.

Such material as silica, dinas-rock, ganister, and ordinary fire-clays contain excess of silica and are acid in character, that is, they tend to combine with bases and form fusible silicates. For some purposes this is objectionable, and basic materials must be used. Of these but four are available: bauxite, lime, magnesia, and the mixture of the two—magnesia lime—obtained by burning magnesian limestone.

Lime occurs in Nature as carbonate in limestones. Magnesian limestone occurs in the north of England, and magnesite (magnesium carbonate) occurs in a few localities. When any of these are heated, carbon-dioxide is expelled, and lime,

magnesian lime, or magnesia, as the case may be, is left. These substances are all basic, but they have no binding power, and lime absorbs moisture and carbon-dioxide so rapidly from the air that a brick or lining made from it would soon fall to pieces. The same action takes place with magnesia or magnesian lime, but to a less extent. The magnesian limestone of the north of England contains about 3 to 5 per cent. of silica, which at a high temperature frits the whole together. In the manufacture of basic bricks hot anhydrous tar is used to hold the material together until this temperature is reached. Basic materials are chiefly used for lining furnaces or converters for the basic steel processes.

The neutral materials used in furnace combustion are graphite or blacklead, and chromite, or chrome iron ore, C_2O_3FeO. These are almost exclusively used in the steel furnace, and therefore do not need more than a mention here.

CHAPTER III.

IRON is present in a vast number of minerals, though its workable ores are not very numerous, and do not differ as widely in their chemical composition and richness as the ores of some other metals. The only minerals worked for the production of iron are either the oxides or the carbonates of iron, accompanied by a gangue, or foreign matters, usually consisting largely of calcareous, siliceous, argillaceous, or bituminous minerals ; and it is upon the nature and quantity of the foreign matter present that the desirability of working the deposit of ore depends. Thus a hæmatite iron ore, though rich in iron, would be of little value, perhaps of no value, if it contained a considerable proportion of a mineral phosphate (as calcium phosphate) or ferrous sulphide (iron pyrites) ; whilst 5, 10, or 15 per cent. of manganese in spathic ores, or of carbonaceous matters in a clay ironstone, would enhance the value of the ore.

The sulphides and silicates of iron occur very abundantly as minerals and metallurgical products, but for reasons to be subsequently explained are not available as ores of iron. Of the oxides of iron used in iron-smelting, the most important are the magnetites, and the red and brown hæmatites, whilst the carbonates include the spathic iron-ores, the argillaceous carbonates known as clay ironstones, and the black band ironstone.

Iron ores occur in almost the whole of the geological series, but most abundantly in the older formations, as the Silurian, Devonian, and Carboniferous, although the brown and argillaceous hæmatites and the carbonates also occur rather largely in the Oolites of Europe.

Native iron, in the form of hard fine-grained buttons known as "native steel," is sometimes found where coal seams have

been ignited in the vicinity of ferruginous deposits ; and
" meteoric iron " is found in large or small masses which have
fallen upon the earth from space outside ; but these are of
such comparatively rare occurrence, irregular distribution, and
small weight, as not to be considered amongst the ores or
sources of iron, as employed in the arts.

Magnetite or magnetic iron-ore is the richest and one
of the most widely distributed of the ores of iron. The pure
mineral is iron-black or iron-grey in colour, it gives a black
streak, is brittle, magnetic, and sometimes distinctly polar ;
it occurs crystallised in the cubic system as octahedra and
dodecahedra, but is more generally found in the massive form,
yielding a crystalline or granular fracture ; and it is also
found in the form of grains or sand. The composition of
magnetite is represented by the formula Fe_3O_4, or Fe_2O_3, FeO ;
when pure it yields 72.41 per cent. of iron, but the two
oxides FeO, Fe_2O_3, are rarely present in any simple atomic
proportion, and the ore usually contains only from 80 to
90 per cent. of the magnetic oxide of iron, accompanied with
from 5 to 15 per cent. of silica. The Swedish magnetites
imported into England are practically free from sulphur
and phosphorus, and some contain considerable proportions
of manganese. Magnetites occur which contain considerable
quantities of both sulphur and phosphorus. These, however,
are only exported after magnetic concentration.

Magnetic iron ore occurs in granite, gneiss, clay-slate, horn-
blende-schist, and other metamorphic rocks, and it is also
often accompanied by red and brown hæmatites. It is
from these ores (magnetites) smelted with charcoal that
the famed Dannemora (Swedish) iron is obtained. The
ore employed at Dannemora yields from 25 to 60 per cent.
of metallic iron, but the average falls below 50 per cent. ;
the ore is accompanied by a gangue, containing silica and lime,
in sufficient quantities to permit of its being smelted with-
out the addition of any further flux to the furnace charge.
Magnetic iron ore is found in considerable abundance in Nor-
way and Sweden, whence it is exported in large quantities ; it
occurs also in Piedmont, Saxony, Canada, the United States,
Mexico, the Urals, Siberia, the Island of Elba, in the West
of England, in Devon, and in Cornwall, but the British
deposits are not worked.

ANALYSES OF MAGNETIC IRON-ORE.

	A	B	C	D	E	F
Ferric oxide (Fe$_2$O$_3$)	27·50	68·98	13·00	72·17	68·8	67·31
Ferrous oxide (FeO)	56·80	—	66·50	2·20	21·7	28·33
Manganous oxide (MnO)	0·24	0·37	0·56	·27	0·16	trace
Alumina (Al$_2$O$_3$)	—	3·81	3·60	·35	—	—
Lime (CaO)	1·80	1·21	0·56	3·42	—	—
Magnesia (MgO)	·80	—	1·52	8·53	—	—
Silica (SiO$_2$)	13·20	24·76	—	10·51	—	—
Phosphoric anhydride (P$_2$O$_5$)	—	0·03	0·57	·024	P.·008	0·07
Ferrous sulphide (FeS$_2$)	—	—	0·04	·029	—	0·09
Water (OH$_2$)	—	—	3·20	1·93	—	TiO$_2$·11
Insoluble residue	—	—	9·40	—	—	3·97
	100·34	99·16	98·95	99·433	—	99·88
Metallic iron per cent.	61·16	—	56·66	53·97	63·84	—

A.—Dannemora ore (Ward). B.—Oural ore. C.—Devonshire (Riley). D.—Persberg. E.—Bispberg (Akerman). F.—British Columbia.

Franklinite is less magnetic than magnetite, which it otherwise closely resembles; it occurs in the metamorphic Silurian limestones of New Jersey, United States. In New Jersey it is first treated for the extraction of zinc, and the residues so obtained are afterwards smelted for spiegeleisen. Franklinite is a mixture of ferric and manganic oxides (Fe, Mn)$_3$O$_4$ with ferrous, manganous and zinc oxide (Fe, Mn, Zn) O, of which Rammelsberg gives as the average of several analyses 45·16 per cent. of iron, 9·38 per cent. of manganese, 20·3 per cent. of zinc, with 25·16 per cent. of oxygen, but the composition is very variable. It is usually regarded as magnetite in which the ferrous oxide (FeO) is replaced by zinc oxide (ZnO).

Chrome Ores.—Chrome iron ore (chromite) may be regarded as being magnetite in which a large proportion of the ferric oxide is replaced by chromic oxide (Cr$_2$O$_3$FeO). These ores have long been used as the source of chromic acid and the chrome salts of commerce. They are also valuable as a neutral material for furnace linings, and since the introduction of chrome steels they have been

smelted for the preparation of chrome iron—an alloy of iron and chromium. Chromite is black in colour, and very closely resembles magnetite in properties ; the streak is browner, and it is less—sometimes not at all—magnetic. It, of course, gives the blowpipe reactions for chromium. Chrome ores are largely imported from Eubea in the Greek Archipelago, Turkey, New Caledonia, and other localities.

Manganese Ores.—Alloys of iron and manganese such as Spiegeleisen and ferromanganese, are now largely made for use in the steel works, and for this purpose large quantities of manganese ores are imported. These ores are black in colour, and consist of one or more of the oxides of manganese, MnO_2, Mn_3O_4, or Mn_2O_3, associated usually with oxide of iron. The principal localities from which these ores are obtained are the United States (principally Michigan and Wisconsin), Brazil, India, and smaller quantities from Greece, Spain, and Germany. The British output is very small.

Hæmatite.—Red hæmatite, which is the base of a most important series of iron ores, consists essentially of anhydrous ferric oxide (Fe_2O_3), and occurs of various shades of colour, from deep red to steel-grey, with a crystalline, fibrous, columnar, botryoidal, or amorphous structure ; the ores occur further in both the earthy and the compact form, as also soft or hard, etc. From the variety of their physical characters the red hæmatites have received special names ; thus, the crystalline variety, occurring at Elba, Brazil, etc., is known to the mineralogist as specular-iron ore or iron-glance, and possesses a bluish or steel-grey colour ; it crystallises in the rhombohedral system, yielding a red streak, and containing, when pure, 70 per cent. of metallic iron. The scaly, micaceous, or foliated variety, which is used as the basis of a paint for iron work, is known as micaceous iron-ore ; and when red hæmatites assume. the form of dull, hard, compact masses, often reniform or kidney-shaped, as occurring in Cumberland, they are then known as kidney ore. The soft and more earthy varieties constitute red ochre, whilst puddler's-mine or ore is the soft, unctuous, compact, earthy form employed for the making and repair of the bottoms of puddling furnaces.

The hæmatite iron ores, owing to their freedom from sulphur and phosphorus, have been in great demand since the intro-

duction of the Bessemer steel process for the manufacture of Bessemer or Hæmatite pig-iron, but hæmatites containing quantities of both phosphorus and sulphur occur in various parts of the world. ·

The following table shows the average composition of some of these ores :—

ANALYSES OF RED HÆMATITE IRON ORES.

	A	B	C	D
Ferric oxide (Fe$_2$O$_3$) . .	94·88	86·50	94·23	85·037
Manganous oxide (MnO) .	0·04	0·21	0·23	—
Alumina (Al$_2$O$_3$) . .	0·07	—	0·51	—
Lime (CaO) . . .	0·34	2·77	0·05	—
Magnesia (MgO) . .	trace	1·46	trace	—
Silica (SiO$_2$) . . .	4·55	—	—	5·130
Carbonic anhydride (CO$_2$) .	—	2·96	—	—
Phosphoric ,, (P$_2$O$_5$) .	0·03	trace	trace	0·032
Sulphuric ,, (SO$_3$) .	—	0·11	0·09	—
Sulphur (S) . . .	—	—	—	0·075
Pyrites (FeS$_2$) . . .	0·47	—	0·03	—
Water (H$_2$O) . . .	—	—	0·56	—
Organic matter . . .	—	—	—	—
Insoluble residue . .	—	6·55	5·18	—
	—	100·56	100·88	—
Metallic iron per cent. .	66·42%	60·55%	65·98%	59·526

A.—Barrow-in-Furness (Richards). B.—Ulverstone (Dick). C.— Ulverstone (Spiller). D.—Canadian.

In the North Lonsdale district the ores average from 52 to 54 per cent. of metallic iron, the highest yielding from 60 to 62 per cent., whilst the poorest contain about 40 per cent.

The most important deposits of red hæmatite are found in the Cambrian, Silurian, Devonian, and Carboniferous rocks ; the deposits of North Lancashire and Cumberland occur in veins in the limestone and Silurian systems, and at Eskdale in granite. Red hæmatite is often associated with the brown oxides, and the ore is classed as hard or soft, according as it contains free silica in excess or otherwise. The more important Continental and foreign deposits of these ores occur in Spain, Canada, and the United States.

Brown Hæmatite.—Brown hæmatite (limonite), or brown

iron-ore, is when pure a hydrated ferric oxide, represented by the formula $2Fe_2O_33H_2O$, and would thus yield 59·89 per cent. of metallic iron. It has a dull lustre, and varies from blackish- to yellowish-brown, but it affords an invariable yellowish-brown streak. It occurs in irregular, compact, more or less homogeneous masses, in the Carboniferous limestone and lower Coal Measures of the Forest of Dean, Gloucestershire, and Glamorganshire ; whilst a less pure variety, containing more or less mechanically mixed sand, occurs in the Lias, Oolites, and Lower Greensands of Northamptonshire, Lincolnshire, Buckinghamshire, and Oxfordshire ; and in all these districts they are oxidised carbonates. Brown hæmatites also are among the most important of the ores smelted in France and Germany. " Bog-iron-ore " is an impure brown hæmatite, smelted in many localities. Associated with limonite, and included under the name brown ores, are göthite ($Fe_2O_3H_2O$) and turgite ($2Fe_2O_3H_2O$).

ANALYSES OF BROWN HÆMATITE IRON-ORES.

	A	B	C	D	E	F
Ferric oxide (Fe_2O_3)	90·05	59·05	56·20	60·72	67·80	60·94
Manganous oxide (MnO)	0·08	0·09	0·20	—	·28	—
Alumina (Al_2O_3)	0·14	trace	2·43		10·19	8·03
Lime (CaO)	0·06	0·25	0·49	11·175	2·80	1·60
Magnesia (MgO)	0·20	0·28	0·17		·59	·06
Silica (SiO_2)	0·92	34·40	29·09	12·66	8·60	13·24
Phosphoric anhydride (P_2O_5)	0·09	0·14	0·84	trace	—	1·02
Sulphuric anhydride (SO_3)	—	—	—	—	—	·08
Sulphur	traces	—	—	0·075	—	—
Pyriets (FeS_2)	—	0·09	—	—	—	—
Water (combined)	9·22	6·14	10·90 {	13·77	}15·35	15·35
„ (hygroscopic)	—	0·24 }		1·60 {		
Metallic iron per cent..	63·04	41·34	39·34	42·5	42·64	42·66

A.—Forest of Dean (Dick). B.—Glamorganshire (E. Riley). C.— Northamptonshire (Percy). D.—New South Wales. E.—Antrim. F.—Lincolnshire.

As previously mentioned, brown hæmatites vary much, both as regards the percentage of metallic iron which they

contain, and also in their freedom from such impurities as phosphorus and sulphur, whilst manganese is almost always present in those ores, and they are accompanied by more or less earthy matter.

Titaniferous iron-ore, or Ilmenite, occurs massive, but is found generally as a dark-coloured or black sand along the shores of the Bay of Naples, the North-east coast of America, Labrador, New Zealand, etc. Certain ferruginous crystalline rocks having been disintegrated, the lighter portions are washed away, whilst the heavier titaniferous particles, or grains, constituting the bluish iron sands, accumulate upon the shore in sufficient quantity to be collected, and, after a preliminary mechanical treatment, to be smelted for the production of iron. The titaniferous sands contain a large proportion of magnetite, besides titaniferous iron-ore, and these are usually accompanied by free silica, with more or less magnesia. Titaniferous iron-ore is a most refractory mineral, and when in a fine state of division is difficult to treat in the blast furnace.

Carbonate Ores.—Ferrous carbonate, $FeCO_3$, is abundant as an iron mineral, and in admixture with various foreign matters forms valuable ores of iron.

The purer varieties are described as spathic ores, whilst the amorphous argillaceous ores of the Coal Measures are known as clay ironstones, and when largely impregnated with carbonaceous or bituminous matter they constitute blackband ironstone.

Spathic Ore.—Spathic ore in its purest form constitutes the crystallised mineral known as siderite, which, when pure, yields 48·27 per cent. of metallic iron. Siderite occurs as a mineral having a pearly lustre, and varying from yellow to brown in colour. but when it occurs in veins exposed to water and atmsopheric influences, it is usually found to have suffered decomposition, and to have become converted into brown hæmatite to a considerable depth from the surface. Spathic ores often contain considerable quantities of manganous oxide, as is the case with the spathic ore of the Brendon Hills, in Somersetshire, which was at one time transported to Ebbw Vale, South Wales, to be smelted for the production of the manganiferous pig-iron known as spiegeleisen The other more important associates of spathic ores are calcium and

magnesium carbonates, with occasionally also quartz, with
copper and lead in small proportion. This ore occurs in
the Carboniferous rocks of Durham, Cornwall, Devon, and
Somersetshire, but more largely on the Continent, as in the
mountain masses of Siegen and Musen, in Rhenish Prussia,
where it is found in rocks of Devonian age ; at Thuringia,
in Hungary, it occurs in Permian rocks ; whilst extensive
deposits also are present in Styria, Westphalia, Lölling, and
Carinthia, in Austria, as also in Hanover and in Russia.

ANALYSES OF SPATHIC AND OTHER IRON ORES.

	A	B	C	D
Ferrous oxide (FeO) . .	43·84	45·86	40·77	39·92
Ferric oxide (Fe$_2$O$_3$) . .	0·81	0·40	2·72	3·60
Carbonic anhydride (CO$_2$) .	38·86	31·02	26·41	22·85
Manganous oxide (MnO) .	12·64	0·96	—	0·95
Alumina (Al$_2$O$_3$) . .	—	5·86	—	7·86
Lime (CaO) . . .	0·28	1·37	0·90	7·44
Magnesia (MgO) . .	3·63	1·85	0·72	3·82
Potash (K$_2$O) . . .	—	—	—	0·27
Silica and insoluble residue	0·08	10·68	—	8·76
Clay	—	—	10·10	—
Phosphoric anhydride (P$_2$O$_5$)	—	0·21	—	1·86
Pyrites (FeS$_2$) . .	—	0·10	—	0·11
Water (OH$_2$) . . .	0·18	1·08	1·00	2·97
Organic matter . . .	—	0·90	17·38	—
	100·32	100·29	100·00	100·41
Metallic iron per cent. .	34·67	35·99	33·57	33·62

A.—Spathic ore, from Somersetshire (Spiller). B.—Clay ironstone
from Dudley (Dick). C.—Blackband, Scotland (Colquhoun). D.—
Cleveland Ironstone (Dick).

Clay ironstone is the argillaceous, amorphous, compact,
or earthy variety of ferrous carbonate, occurring either in
detached nodules, or in layers of nodular concretions, dis-
tributed through the shales and clays of the Coal Measures,
or in beds of considerable thickness in Liassic rocks. These
consist of ferrous carbonate mixed with a considerable quantity
of clayey matter, or perhaps rather are beds of clay which
have become saturated with carbonate of iron. The iron may
be evenly distributed through the bed, or it may be collected
into concretionary masses.   When not discoloured by

admixture with carbonaceous matters or by atmospheric de-
composition, they range in colour from light grey or yellow
to brown, but the lighter coloured varieties rapidly become
brown on exposure to the atmosphere; they are always
impure, containing in addition to the clay appreciable
quantities of calcium, magnesium, and manganese carbon-
ates, phosphoric acid, iron pyrites (FeS_3), and occasionally
also other minerals, as blende (ZnS) and galena (PbS). The
principal localities in which they occur are the Coal Measures
of North and South Staffordshire, Derbyshire, Yorkshire,
Warwickshire, Shropshire, North and South Wales, Den-
bighshire, and in Scotland.

Blackband ironstone is ferrous carbonate associated with
from 15 to 25 per cent. of bituminous, coaly, or other carbon-
aceous matter, which gives it almost the appearance of coal—
it is, in fact, a bed of coal which has become saturated with
ferrous carbonate; it occurs in beds most largely in the
coalfields of Lanarkshire and Linlithgowshire, to a smaller
extent in North Staffordshire, and also in South Wales.
Owing to the large amount of carbonaceous matter contained
in this ore, it can be calcined in heaps without the addition
of any further fuel, and the calcined product yields from
50 to 60 per cent. of metallic iron.

Other earthy and metallic impurities are always present,
and the ore always contains a considerable quantity of phos-
phorus. Black band ores were discovered in Scotland by
Mushet, in 1801, and when the hot blast was introduced they
came rapidly into use and " made " the Scotch iron industry.
The Scotch deposits are now almost exhausted.

Cleveland Ironstone.—This is one of the most important
ores now raised in this country. It was first worked about
1850, and it has led to the development of Middlesbrough
into the most important iron-producing district in the country.
It is an impure carbonate, the carbonate being associated with
calcium carbonate and other earthy matters. The beds
seem to be beds of an oolitic limestone in which the calcium
carbonate has been replaced by ferrous carbonate. The beds
belong to the Liassic series. They are very fossiliferous,
the two main beds being distinguished by the names of
the predominant fossils, the Avicula and Pecten beds. The
total thickness of the beds is about 15 ft. The mines are on

c

the Cleveland Hills, a few miles behind—that is, south of Middlesbrough—so that the ore can easily be brought down to the town.

The ore is more or less granular or oolitic in structure, and usually of pale bluish-green colour, due to the presence of ferrous silicate ; but some varieties are darker.   One bed at Rosedale Abbey, now exhausted, was very dark—nearly black —and was magnetic from the presence of magnetic oxide. One of the most important characters of the ore is the large quantity of phosphorus always present, owing to the very fossiliferous character of the rock.   Ores very similar in character to those of Cleveland are now being worked in other places. The readiness with which the carbonate passes into the hydrate under the influence of air and moisture has already been explained, and in many cases where surface deposits of brown ore have been worked through, carbonate has been found underlying.   This has been the case in Northamptonshire. In Lincolnshire extensive beds of fossiliferous carbonates of the Lias age are now being worked, and an extensive iron industry is growing up there in consequence.   The ores are high in phosphorus, yellow and green in colour, and are not unlike those of Cleveland.   The workable beds are about 16 ft. in thickness

Imported Iron Ores.—With the introduction of the Bessemer process for steel-making there arose a great demand for pig iron free from sulphur and phosphorus, and this could only be made from ores free from these elements.   As the only British deposits of suitable material—those of North Lancashire and Cumberland—were quite inadequate to meet the demand, ironmasters had to seek other sources of supply. The enormous development of the iron industry during the last thirty or forty years has also necessitated a supply of ore greater than the home mines could yield, so that the world has been searched for suitable ore deposits, and an immense import trade in iron ore has grown up.

Among the most important of the districts supplying iron ore is Bilbao, in Spain, from which district about 8,000,000 tons of ore is annually exported.   The ores are red and brown hæmatites and carbonates, the brown ore being due to surface oxidation of the deeper-lying carbonate.   Four varieties of ore may be mentioned :—

(1) Vena.—A dark purple ore, very soft, and yielding about 60 per cent. of iron. It occurs only in small quantity.

(2) Campanil.—A dark red ore, yielding about 55 per cent. of iron, the gangue being mainly carbonate of lime. This ore has been largely used both for smelting and in the open-hearth steel furnace, but the supply is now nearly exhausted.

(3) Rubio.—A brown or yellow ore occurring in lumps which often have a vesicular structure. Being a brown ore, it contains a considerable quantity of water, and yields about 50 per cent. of iron. The gangue is siliceous.

(4) The carbonate ore is now being largely worked. It has an oolitic structure, and is always calcined before export.

All these ores are free from sulphur and phosphorus. Iron ores occur, and are extensively worked, in many other parts of Spain : Carthagena, Almeira, Sevilla, Huelva, and other locali-ties may be mentioned. The ores are sometimes black (mag-netites), more often red (hæmatites), but generally brown ores, and they are usually free from sulphur and phosphorus. Iron ores are also imported from Canada, from Cuba, from Norway and Sweden, from Elba, and many other localities. Imported ores are not now always phosphorus-free, as for some purposes there is a demand for phosphoric ores.

The following analyses will give an idea of the character of the imported ores :—

	A	B	C	D	E	F
Iron	58·80	55·49	68·50	48·26	58·61	46·56
Manganese	1·47	·70	Trace	3·51	—	1·82
Silica	3·20	8·88	2·50	7·00	5·42	3·08
Lime	4·60	Trace	—	2·44	—	8·22
Sulphur	—	·012	·040	·017	·276	·046
Phosphorus	Trace	·012	·018	·014	·017	·016
Copper	—	—	—	—	—	·019
Moisture	6·00*	10·30	Trace	2·50	1·50	6·50

A.—Campanil. B.—Rubio. C.—Gellivara. D.—Almeira, Spain. E.—Mokla, Algeria. F.—Seriphos, Greece.

* And carbon dioxide.

Output and Consumption of Ore in the United Kingdom.
—In order that the student may understand to what extent Great Britain is at present dependent on foreign ore supply

and the wide field from which this is derived, the following figures for the year 1904 are given :—]

The total amount of iron ore raised in Great Britain was 13,774,282 tons, of which the output was from :

	TONS.
Cleveland	5,758,510
Scotland	838,104
Staffordshire	818,468

The ore imported, including chrome ore, was from :—

	TONS.
Sweden	238,256
Norway	281,862
Germany	2,534
Holland	11,450
Belgium	9,410
France	172,950
Portugal	6,045
Spain	4,648,355
Italy	—
Greece	344,555
Turkey, European	6,961
Turkey, Asiatic	2,802
Algeria	237,744
Persia	2,441
United States	5,317
Other Foreign Countries . . .	79,145
Total from Foreign Countries . . .	6,649,807

From British Possessions :—

Australia :	
Victoria	78
New South Wales	4,115
Canada	22,290
Newfoundland	18,217
Other British Possessions	6,429
Total from British Possessions . . .	51,129

Total imports from all sources, 6,700,746 tons, or, roughly speaking, of the total ore used about one-third is imported. If it were measured by the amount of iron produced the proportion would be much larger, since the imported ores are in general much richer in iron than those raised at home.

In the year 1904 the amount of manganese ore imported

was 205,175 tons, of which 95,840 tons came from Russia, 52,620 tons from Brazil, and 27,970 tons from India, whilst only 3,971 tons came from Greece.

American Iron Ores.—The immense development of the American iron industry during the last twenty-five years has been largely due to the discovery of immense deposits of rich and easily-worked iron ores. Iron ores of all kinds are widely distributed in the United States, but, as a rule, only the richer varieties, such as magnetites and red and brown ores are smelted. The most important ores at present worked are the hæmatites of the Lake Superior District, about 75 per cent. of the iron made in the United States being made from these ores. The ores come to the surface in thick beds, and are often worked by quarrying, steam navvies being largely employed to lift the ore and transfer it to the railway trucks.

In the year 1903 the output in the Lake Superior district was :

						TONS.
From the Marquette Range	.	.	.	.	3,040,245
„	Menominee	„	.	.	.	3,749,567
„	Gogebic	„	.	.	.	2,912,912
„	Vermillion	„	.	.	.	1,674,699
„	Mesabi	„	.	.	.	12,892,542
	Total	.	.	.	.	24,271,965

the total output of the United States for the year being 32,471,550 tons. The ores are low in sulphur and phosphorus, and the iron is made of the Bessemer or Hæmatite quality. In the Southern States hæmatite ores occur which contain phosphorus, and are therefore used in the manufacture of foundry pig.

Classification of Iron Ores.—Iron ores may be classified in various ways. A convenient classification is that based on the mineral which forms the basis of the ore :—

Black ores	contain	Magnetite.
Red ores	„	Hæmatite.
Brown ores	„	Limonite.
Carbonate ores	„	Carbonate.

For practical purposes ores are often classified into non-phosphoric and phosphoric. Non-phosphoric ores are such

as contain less than ·06 per cent. of phosphoric anhydride, such as the Cumberland and North Lancashire Hæmatites, Bilbao ores, etc. Phosphoric ores contain more than ·60 per cent. of phosphoric anhydride, such as Cleveland ores, Blackland ores, Clayband ores, etc. Or they may be classified according to the nature of the gangue associated with the iron mineral :—

(1) Siliceous Ores.—Those in which the gangue is mainly silica—*e.g.* the Cumberland, North Lancashire Hæmatites, most Spanish ores, etc.

(2) Calcareous Ores.—In which the gangue is mainly carbonate of lime—*e.g.* Campanil ore.

(3) Aluminous Ores.—In which the gangue is mainly alumina—*e.g.* Belfast aluminous ore.

(4) Argillaceous Ores.—Those in which the gangue is mainly clay—*e.g.* Clayband ores.

(5) Bituminous Ores.—Those in which the gangue contains a large quantity of bituminous or coaly matter—*e.g.* Blackband ores.

This classification is very convenient for smelting purposes.

CHAPTER IV.

PURE metallic iron, as already stated, is a body difficult of preparation, especially in the compact state, except by laboratory methods, and the pure metal is not therefore a substance of commercial importance ; but in combination with variable but small proportions of carbon, and other metallic and non-metallic elements, such as sulphur, silicon, phosphorus, manganese, etc., it constitutes the various qualities of pig-iron, steel, and malleable-iron. The chemical symbol for iron is Fe, and its atomic weight is 56.

Pure iron is prepared by the electrolysis of ferrous chloride ($FeCl_2$), by the reduction of ferric oxide (Fe_2O_3), or of ferrous chloride, by heating either of them to redness in a tube through which a current of hydrogen gas is passed ; or in a nearly pure state it can be obtained by the fusion under a layer of glass free from metallic oxides, of fine iron wire or iron filings, with artificially-prepared magnetic oxide of iron. Iron as prepared by the last method is a metal varying in colour from bluish-grey to silver whiteness according to the state of its aggregation ; as reduced from ferric oxide by hydrogen, it forms a grey powder, which is pyrophoric (that is, takes fire spontaneously on exposure to the atmosphere) if the temperature employed in its production has not exceeded dull redness ; but it no longer possesses this quality if the temperature employed in its preparation has exceeded this limit. As obtained from ferrous chloride ($FeCl_2$), the metal yields well-defined cubical crystals, and it is always crystalline after fusion. Iron is capable of receiving a high polish, it is very tenacious, ductile, and malleable, the last quality being unaffected by heating and subsequent rapid cooling, neither is it hardened by this treatment; Electro-deposited iron absorbs or occludes hydrogen to the extent of from seventeen to twenty times its own volume.

Magnetism of Iron.—One of the most striking properties of iron, in which it excels all other elements, is its power of becoming magnetic. If a piece of nearly pure iron be brought into a magnetic field, it at once becomes magnetic to a much higher degree than the field in which it is placed. Its magnetic permeability is therefore said to be high. It seems to concentrate the surrounding magnetism into itself. Immediately it is taken out of the magnetic field the magnetic power is lost—that is, it is not retained by the iron, or its magnetic retentivity is almost nil. At a high temperature—about a red heat—the magnetic permeability is completely lost, and the iron ceases to be magnetic. The presence of foreign elements in the metal greatly modifies its magnetic properties. A small percentage of carbon decreases the permeability, but increases the retentivity, so that permanent steel magnets can be made, whilst a considerable percentage of manganese destroys both properties.

Pure iron is softer than the commercial varieties of malleable iron, and has a specific gravity of 7·87. Its melting point does not appear to have been accurately determined, for whilst Pouillet estimates it at from 1,500° C. to 1,600° C. (2,732° F. to 2,912° F.), Scheerer gives it as 2,100° C. (3,812° F.), but the presence of small quantities of carbon in combination with the metal rapidly lowers the melting point.

Iron is unaffected by dry air at ordinary temperatures (except in the pyrophoric or spongy state already described), or in perfectly pure water free from air, oxygen, or carbonic anhydride ; but if exposed to a moist atmosphere, then the oxidation commonly known as rusting rapidly proceeds, if carbon-dioxide is also present, as it always is, in the atmosphere. The presence of carbon-dioxide appears essential to the rusting of the iron by moisture, since the metal may be kept bright for almost any length of time in pure lime water, or in a solution of soda. Under the joint influence of moisture, oxygen, and carbon-dioxide, ferrous carbonate is first produced on the surface of the iron, but this, by absorbing a further proportion of water and oxygen, becomes changed to a hydrated ferric oxide, with the liberation of carbon-dioxide, which latter then reacts upon a fresh portion of the iron in the presence of water and oxygen, and a further quantity of ferrous car-

bonate is produced, and so the cycle continues to be repeated. Further, the hydrated oxide, or rust, is electro-negative with respect to the metallic iron upon which it is formed, and the electrical condition thus resulting still further promotes the action of oxygen on the metal, and the corrosion of the iron thus proceeds rapidly. Water holding carbon anhydride and free oxygen in solution rapidly attacks and oxidises metallic iron. Iron, when heated to rednes⁁ in contact with air or oxygen, is rapidly oxidised, with the production of a black scaly oxide readily detachable from the surface of the iron. This oxide constitutes, on the large scale, the hammer-scale or hammer-slag of the forge, and is mainly the magnetic oxide Fe_3O_4. Iron at a red heat decomposes water with the liberation of hydrogen and the formation of Fe_3O_4.

Hydrochloric acid attacks metallic iron with the formation of ferrous chloride ($FeCl_2$) and the liberation of free hydrogen. Concentrated sulphuric acid (H_2SO_4) also attacks the metal with the liberation of sulphur-dioxide (SO_2), whilst ferrous sulphate ($FeSO_4$) crystallises out; but if the diluted acid be employed, then hydrogen is liberated, and ferrous sulphate remains in solution. The action of nitric acid upon iron, at the ordinary temperature, varies with the degree of concentration of the acid. Thus, ordinary nitric acid attacks iron vigorously with the evolution of nitrous fumes in abundance, but if the acid be dilute there is no sensible escape of gas, and ferrous nitrate $Fe(NO_3)_2$ and ammonium nitrate (NH_4NO_3) occur in solution; thus ($10HNO_3 + 4Fe = 4Fe(NO_3)_2 + NH_4NO_3 + 3H_2O$) strong-fuming nitric acid is without action upon the metal, a bright surface of which may be introduced into the cold concentrated acid without inducing any chemical decomposition, in which case the surface of the metal on immersion assumes a dull whitish appearance, and no further action ensues, the metal having assumed what is known as the passive condition.

Iron Oxides.—Four oxides of iron are known. Corresponding hydrates of some of them exist, and two form the starting point of a series of salts. The important oxides are the ferrous oxide (FeO), ferric oxide (Fe_2O_3), and the intermediate black oxide (Fe_3O_4).

Black oxide (Fe_3O_4) is a magnetic substance obtained by heating iron to redness in steam. Hammer-scale, obtained by heating iron in air, is not uniform in composition or physical character. The outer layer of scale is found to be strongly magnetic, almost metallic in lustre, brittle, fusible only at the highest temperatures, more highly oxidised, and somewhat redder in colour than the inner layers, which are less lustrous, spongy, tougher, and less magnetic than the outer layers. Magnetic oxide (Fe_3O_4) is the oxide of iron entering most largely into the composition of the scale, but there is also a variable excess of ferric oxide (Fe_2O_3), and hence the varying physical qualities of the scale. Magnetic oxide occurs native as the black mineral known as magnetite.

When the magnetic oxide is dissolved in acids a mixture of ferrous chloride ($FeCl_2$) and ferric chloride (Fe_2Cl_6) results, the proportion of the two salts being the same as that of the oxides in the substance dissolved.

Magnetic oxide is sometimes regarded as being a mixture or molecular combination of the other two oxides.

Ferric oxide (Fe_2O_3) is a very stable and practically fixed oxide of iron, decomposable, however, at a white heat, with the liberation of oxygen and the production of the magnetic oxide ($3Fe_2O_3 = 2Fe_3O_4 + O$). Ferric oxide is produced when ferrous sulphate is strongly heated, the salt suffering decomposition with the elimination of sulphur-dioxide (SO_2) and sulphuric anhydride (SO_3), whilst a bright red pulverulent powder, forming the rouge or colcothar of commerce, is obtained, which has the composition of ferric oxide. Ferric oxide is decomposed with the reduction of metallic iron by heating it in a current of carbonic oxide (CO) or hydrogen, or by heating it with carbon. Ferric oxide after ignition is only slowly acted upon by either hydrochloric, nitric, or sulphuric acid, but previous to ignition it is readily soluble in these acids with the production of stable ferric salts ; if heated with an excess of sulphur, sulphur-dioxide (SO_2) is evolved, and ferrous sulphide (FeS) is obtained.

Ferric oxide is prepared in the laboratory by heating to redness ferrous nitrate, oxalate or sulphate, or a mixture of ferrous sulphate and sodium chloride ; whilst it occurs in

nature in sufficient abundance to be worked as the mineral hæmatite.

The hydrated ferric oxide ($2Fe_2O_3,3H_2O$) is the most stable of the hydrated oxides of iron, and occurs native as brown hæmatite or limonite. The freshly precipitated oxide obtained by adding potash, soda, or ammonia, to a solution of a ferric salt, is an amorphous, brownish-red body, readily soluble in acids, and even slightly soluble in water containing carbon-dioxide in solution, and having the composition $Fe_2O_33H_2O$, but after remaining precipitated for some time, or by boiling with water during six or seven days, it loses two equivalents of its water of composition, retaining but one equivalent, assuming thereby a more brick-red colour, and becoming only slightly soluble in the mineral acids.

Iron rust is essentially hydrated ferric oxide of variable composition, produced on the exposure of metallic iron to the joint action of air, water, and carbon-dioxide.

Ferrous oxide (FeO) is of little metallurgical importance. It is a very unstable body, and even if it has ever been obtained pure oxidises so readily that it is of no practical importance, but it is the starting point of the ferrous salts in which iron exists in the ferrous condition, such as the carbonate $FeCO_3$, the sulphate $FeSO_4$, etc. Clay-ironstone contains a large proportion of ferrous carbonate, and it exists in a still larger proportion in the crystallised ores such as siderite or spathic iron-ore. In combination with silica, it forms ferrous silicate ($2FeO,SiO_2$), which enters largely into the composition of the various slags, cinders, etc., produced in the metallurgical treatment of iron. The hydrated oxide or ferrous hydrate is precipitated as a white flocculent precipitate, when potash or soda is added to a solution of a ferrous salt; but the precipitate rapidly changes from white to green and then to brown, owing to the absorption of oxygen.

A fourth oxide is ferric anhydride, which in combination with water is known as ferric acid (H_2FeO_4), is not of metallurgical interest, since it has not been obtained in the free state. Its alkaline salts result in small proportion when nitre and iron filings, or nitre and ferric oxide, are heated to dull redness and are very unstable; they rapidly

and spontaneously decompose with the liberation of oxygen and the separation of ferric oxide.

Compounds of Carbon and Iron.—Iron and carbon combine readily under various conditions, and the importance of these combinations is so great commercially that they must be somewhat fully considered.

When iron is melted with carbon, as in the blast furnace, the carbon is absorbed until about 4·5 per cent. is present. The same result may be obtained, though more slowly, by heating iron to the welding temperature in presence of solid carbon, as in the cementation process of making steel. Indeed, carbon and iron combine so readily that it is almost impossible to prepare perfectly carbon-free iron.

Pig iron containing about 4·5 per cent. of carbon, the maximum which it can take up, is not a definite compound. Up to the present only one definite compound of carbon has been proved to exist—Fe_3C, which was discovered by Professor Abel, and is therefore often called " Abel's Carbide," which contains 93·23 per cent. Fe. and 6·67 per cent. C.

Another carbide—$Fe_{24}C$, containing ·89 per cent. carbon —has been suggested, but its existence has not been proved. If it is not a definite carbide, it is certain that carbon can exist to this amount in a state of solid solution in iron. Carbon exists in commercial forms of iron in at least three forms.

(1) **Graphite.**—When a mass of highly carburised iron—say a pig-iron containing about 4 per cent. of carbon—is allowed to solidify, at the moment of solidification, or immediately after the metal has become solid, a large proportion of the carbon may be ejected in the form of flat black, glistening flakes of graphite. It is certain that in the liquid metal all the carbon was either in solution or combination, or being so much lighter than the iron, it would have floated to the top, and as the flakes of graphite are very uniformly distributed the separation must have taken place after the mass had become so solid that the flakes could not float upward.

Such an iron would be a grey iron. Much of the carbon would be present in the form of graphite, which, if a sample of the iron were dissolved in acid, would be left in the insoluble residue, since graphite is unacted on by acids, whilst the small portion in combination would escape.

(2) **Combined Carbon.**—When a sample of steel is dissolved in acid there is no residue of graphite, the whole of the carbon present passing away in the gaseous form with the evolved hydrogen. The carbon is present, therefore, in the combined condition, and not in the form of graphite ; but it is found, further, that the behaviour of the carbon in a steel to certain solvents may vary according to the character of the steel, and that the properties of the steel itself will vary very much according to which of the two forms the carbon is present in.
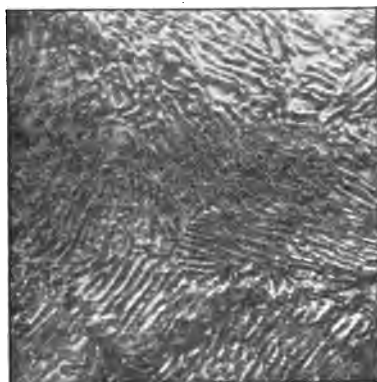
Fig. 12.—Pearlite Magnified about 500 Diameters.

Carbide Carbon.—When the steel is cooled slowly and then dissolved in some acid or other solvent which does not evolve hydrogen—a mixture of chromic and sulphuric acids being usually used—the carbon is left in the form of a definite carbide (Fe_3C), and carbon in this form is always spoken of as carbide carbon.

Hardening Carbon.—If the steel be heated to redness and then suddenly quenched, it becomes intensely hard, and if now it be dissolved as before, the carbon is not left as carbide, but disappears by oxidation or otherwise. As the carbon present in this form hardens steel it is called hardening carbon.

Thus carbon may exist in iron in three forms :—(1) Graphite. (2) Combined carbon (*a*) carbide carbon; (*b*) hardening carbon.

In order to learn more about these forms of combined carbon, other than purely chemical methods must be used, and in the microscope the necessary instrument has been found.

If a piece of iron containing about ·89 per cent. of carbon and no other impurities be heated to redness and slowly cooled, and then be suitably polished, etched, and examined under the microscope, it is found to show a very peculiar structure (shown by Fig. 12). It is seen to be made up of a series of more or less parallel bands of two substances ; the one, much harder than the other, resists abrasion and the action of etching agents much more strongly, and so stands up in relief.

Of these two substances—

(1) The harder one is the carbide (Fe_3C), or, as it is called in the language of metallography, Cementite. This is an intensely hard body.

(2) The softer one is pure iron, Fe, or, as it is known in this connection, Ferrite.

The compound body made up of the two is called Pearlite. Though pearlite seems to be only a mechanical mixture it has a definite composition, and contains ·89 per cent. of carbon. As cementite contains 6·67 per cent. it is obvious that pearlite consists of about 13·35 per cent. of cementite and 86·65 per cent. ferrite. The percentage of cementite is the percentage of carbon $\times$ 15.

The maximum amount of carbon which can be held by solid pure iron is about 4·5 per cent., but that amount may be increased by the presence of other constituents.

If the sample of metal be heated to redness, chilled in water, and then polished and etched as before, an entirely different structure is seen. The pearlite has disappeared. The metal looks almost structureless, but faint feathery crystals may be detected. The carbon here has not separated, but has remained distributed through the whole of the mass, probably in the form of a solution ; and as the solvent iron in this case is solid and not liquid, it is called a solid solution. This form is called Martensite.

If now a sample of metal containing less carbon than ·89 —say ·2 per cent.—of carbon be heated, slowly cooled, and etched as above described, and this examined, it will be found

that there are only small particles of pearlite, which are surrounded by masses of ferrite. It will be seen that there is not enough carbon to convert all the iron into pearlite, so that the balance will be left as ferrite. If the sample be quickly cooled, the sample will consist of Martensite, and perhaps ferrite.

If now a sample containing more than ·89 per cent. of carbon —say with 1·2 per cent. of carbon—be slowly cooled, the main portion of the mass will be found to be made up of pearlite ; but obviously there is now more than enough carbon to form pearlite. The excess will remain as fragments or filaments of cementite scattered through the pearlite.

Carbon, therefore, may be present in iron as—(1) Intermixed graphite. (2) Cementite in pearlite. (3) Cementite in excess of that required to form pearlite or structurally free cementite. (4) Martensite, which may or may not be associated with excess of cementite or ferrite.

The conditions under which the carbon can exist in each form, and the changes produced in the properties of iron by variations in the form in which the carbon is present will be discussed fully in the companion volume which treats on " Steel : its Varieties, Properties, and Manufacture."

Ferrous carbonate ($FeCO_3$) is metallurgically one of the most important salts of iron, since the anhydrous ferrous carbonate occurs crystallised as siderite or spathic iron ore, and in the other varieties of carbonate ores which have been described. On p. 40 it is explained how ferrous carbonate was produced by exposing iron to the joint action of atmospheric air or oxygen, moisture and carbonic anhydride (CO_2), and how by further exposure the ferrous carbonate was again decomposed, with the deposition of hydrated ferric oxide, or iron-rust. Ferrous carbonate is slightly soluble in water, but more so in water containing free carbon-dioxide, and this solution on exposure to the atmosphere suffers decomposition, with deposition of the hydrated ferric oxide as before mentioned. Ferrous carbonate is also decomposed at a red heat in the absence of air or oxygen, with the production of red oxide of iron and the liberation of carbon dioxide and carbon monoxide the $2FeCO_3 = Fe_2O_3 + CO + CO_2$, or if the temperature be higher with the production of magnetic oxide of

iron (Fe_3O_4), and the liberation of carbon-monoxide (CO) and carbon-dioxide, thus : $3(FeCO_3) = Fe_3O_4 + 2CO_2 + CO$.

Compounds of Sulphur.—Several sulphides of iron are known. The direct combination of sulphur and iron results when these elements are brought into contact under the influence of heat, the combination being attended with a considerable evolution of heat, ferrous sulphide (FeS) being formed.

Ferrous sulphide (FeS) is the ordinary sulphide of iron of commerce, but it does not occur free in nature. It can be prepared artificially, as previously mentioned, by the direct union of sulphur with iron at a red-heat ; by heating to redness ferrous sulphate in a charcoal-lined crucible ; by the ignition of hammer-scale with sulphur ; or by the precipitation of a ferrous salt by an alkaline sulphide. As artificially prepared by the dry methods above enumerated, it forms a dark brown or black body, having a semi-metallic lustre. It is not sensibly affected by exposure to the atmosphere at ordinary temperatures ; but, if heated, as in the operation of roasting, it is oxidised and ferrous sulphate and ferric oxide results. At a higher temperature, the ferrous sulphate is decomposed with the production of ferric oxide (Fe_2O_3) and the liberation of sulphur-dioxide and sulphur-trioxide. When heated with carbon, ferrous sulphide is but slightly acted upon ; when heated with ferric oxide, part of the sulphur passes off as sulphur-dioxide, but there is no reduction of metallic iron. Ferrous sulphide is not affected by heating with silica alone, but if carbon be also present the ferrous sulphide is largely decomposed.

Iron Pyrites. — Iron disulphide (FeS_2) is a familiar brass-yellow mineral occurring in many forms, having a strong metallic lustre, and known generally as yellow iron pyrites, cubic pyrites, or mundic. It crystallises in the cubic system, good crystals being quite common. It also occurs massive in vast quantities, and is largely used under the name of sulphur ore for the manufacture of sulphuric acid. It is of no use directly as an ore of iron, but the residues left on burning the pyrites in the manufacture of sulphuric acid, known as blue billy or burnt ore, or after the copper has been extracted as purple ore, are used in the ironworks. Marcasite

or white iron pyrites, has the same composition as iron pyrites, from which it differs by its pale colour and its different crystalline form. Heated without access of air, either form of disulphide is decomposed, sulphur being evolved, and a sulphide of uncertain composition left: $2FeS_2 = Fe_2S_3 + S$ or $FeS_2 = FeS + S$. In presence of air the sulphur is oxidised, thus: $2Fe_2S_3 + 11O = Fe_2O_3 + 4SO_2$; or at lower temperatures, $FeS_2 + 6O = FeSO_4 + SO_2$, the iron sulphate being decomposed on further heating. Both pyrites and marcasite are oxidised on exposure to moist air, various products, such as ferric oxide or ferric sulphate, sulphuric acid, etc., being formed. Marcasite oxidises far more readily than pyrites.

Magnetic pyrites or pyrrhotine (Fe_3S_4) occurs native, associated with the ores of nickel and copper, but it has no special metallurgical importance.

Iron and phosphorus readily unite under the influence of heat, producing grey fusible phosphides. A ferrous phosphide results when ferrous phosphate is heated to a high temperature with carbon.

Of the various phosphides of iron that can be prepared by purely chemical methods only one—that having the formula Fe_3P and containing 15·58 per cent. of phosphorus, is of any metallurgical importance. This phosphide dissolves in metallic iron, and if there be less than about 1·7 per cent. of phosphorus, the iron will retain this in solid solution. The presence of such phosphorus tends to produce crystals of large size. If the quantity of phosphorus be above 1·7 per cent., the excess of phosphide will separate as a definite eutectic containing about 10 per cent. of phosphorus and melting at about 980° C. This eutectic consists of the phosphide Fe_3P and metallic iron, and of course can be detected under the microscope. The amount of phosphorus than can be held in solution is very much modified by the presence of other elements, and will be discussed when cast-iron is being considered. When iron containing phosphorus is treated with hydrochloric acid a portion of the phosphorus is eliminated as phosphoretted hydrogen, PH_3.

Eutectic.—When an alloy of two or more metals solidifies, changes other than a mere solidification usually take place, though the exact character of the changes will depend on the

D

metals present. For example, assume the alloy to consist of
two elements, A and B, the quantity of B being larger than
A can retain in solution in the solid condition. Then as
solidification goes on, A with some B in solution will solidify
and some B will be thrown out, so the mother liquor is growing
constantly richer in B. At last a point is reached when the
two constituents of the mother liquid will solidify together.
They will then so solidify, not as one substance, but as layers
or masses of the two separate substances, forming a eutectic.
The eutectic mixture is the alloy of lowest melting point of
the series. In structure if often closely resembles pearlite.
Though pearlite has this distinctly eutectic structure, it is
not a eutectic, because it is not formed during solidification,
but after the metal has actually become solid.

Iron and Silicon.—Silicon and iron unite in various pro-
portions, and definite silicides are known. The silicide dis-
solves readily in metallic iron, and when silicon is present in
an iron it is present in solid solution in the ferrite, and there-
fore cannot be detected by the microscope. Silica is always
present in furnace charges, and being partially reduced at
the temperature of the furnace, silicon passes into the iron.
There does not seem to be a definite limit as to the quantity
of silicon which can be taken up under suitable conditions.
Irons containing 15 per cent. or more of silicon are regu-
larly made.

Silica and ferrous oxide, or ferric oxide, in presence of
reducing agents, unite readily, forming ferrous silicates. Of
the silicates the most fusible and probably the most stable is
the monosilicate ($2FeO$, SiO_2), Fe_2SiO_4. This is fusible at a
bright red heat, and solidifies to a black, more or less glassy
mass. It constitutes a large proportion of the slags pro-
duced in puddling and similar operations, and in the smelting
of lead and copper ores in the blast furnace. When this silicate
is roasted with free access of air, it is broken up into ferric
oxide and silica ($Fe_2SiO_4 + O = Fe_2O_3 + SiO_2$), and as these
do not unite, a refractory mixture called Bull Dog results.
In a reducing atmosphere, however, the ferric oxide is reduced
to the ferrous condition, and the fusible silicate is reproduced.
The silicates containing less iron, such as the bisilicate
(FeO,SiO_2), $FeSiO_3$, are rarely produced in metallurgy.

Iron and nitrogen unite to form two or more distinct

nitrides of iron. When iron-wire is heated to redness for some hours in a current of dry ammoniacal gas, the wire so treated is stated to gain slightly in weight, to be more brittle, and less alterable by exposure to the atmosphere than pure iron, and to become also whiter in colour ; Savart says that after attaining to this condition, if it be longer exposed to the ammoniacal vapour, the metal assumes a dark-grey colour, becomes soft, has a graphitic fracture, and will not harden in water. The evidence as to the exact increase in weight of the iron by the above treatment is very contradictory, the statements ranging between 0·2 to 12 or 13 per cent., and from such evidence it is impossible to state whether nitrogen does or does not play any important part in the process of cementation for the conversion of bar-iron into blister-steel.

Whether nitrogen exists in combination in iron is very uncertain. Nitrogen can usually be obtained from iron, but it is probably present merely in the form of dissolved gas. At any rate, it does not appear to have any influence on the quality of the metal.

Alloys.—Iron and many of the other metals unite with great facility to form alloys ; thus, for instance, when the ores of iron and of a second metal are simultaneously reduced, an alloy of the two metals often results, though with but few exceptions these alloys are without commercial importance.

Manganese is a constant constituent of pig-iron and of steel, and the metals seem to alloy in all proportions. Spiegeleisen is a pig-iron containing from 8 to 30 per cent. of manganese, and is a regular article of commerce ; whilst alloys known as ferro-manganese, containing from 80 to 85 per cent. of manganese, are manufactured in large quantities for use in the production of mild steel, by the Bessemer and Siemens processes. The presence of manganese in iron ores favours the elimination of sulphur from the pig-iron produced from such ores.

Tungsten and iron unite readily, when tungsten is reduced from its compounds by carbon in the presence of metallic iron, but a very high temperature is required for the reduction.

Chromium alloys with iron, producing ferrochrome, which is now made on a large scale, containing up to about

65 per cent. of chromium. This alloy is used in the pre-
paration of chrome steel.

Copper does not readily unite with iron to produce a
homogeneous alloy by the simple fusion of any mixture of
the two metals, but if iron be added in small quantities to
brass or bronze in a state of fusion it is readily taken up, and
the resulting alloy has a higher tensile strength than the
original brass. Copper in small quantities does not seem to
have any injurious influence on iron, whether it is to be used
in the foundry or for steel making.

Zinc and iron yield, when heated together, more or less
crystalline, brittle, and friable alloys, which, however, are
without practical application to the arts, and are more properly
zinc alloys, since about 7 per cent. is the maximum amount of
iron that molten zinc will take up ; but the manufacture of
galvanised or zinced plates—that is, steel plates coated with
a thin layer of zinc, or with an alloy of zinc and iron—is now
in itself an important industry. Galvanised plates, whilst
possessing the strength due to the steel, are not so readily
affected on exposure to atmospheric influences by rusting
or corrosion, so long as the zinc coating remains intact.

Tin and iron unite when heated together, and produce grey
or white alloys, which are harder than tin, and break with a
crystalline or granular fracture. Alloys of the two metals
in almost any proportions may be obtained, but like the alloys
of zinc, they are also without practical application to the arts,
but a layer of metallic tin is readily applied to an iron or
steel surface as in the manufacture of tin plates. Small quan-
tities of tin in malleable-iron or steel render it cold-short, and
also only workable with great care even at a red-heat, the
metal being brittle and difficult to weld.

Antimony can be readily alloyed with iron, but its presence
in wrought-iron, to the extent of only 0·2 or 0·3 per cent., is
sufficient to render the iron both red-short and cold-short.

Nickel alloys readily with iron, by the direct fusion of the
two metals, or by reducing a mixture of their oxides. The
presence of nickel in iron does not affect its malleability, but
the alloy is whiter in colour than pure iron, is not so easily
affected by exposure to air or moisture, and takes a better
polish than iron. A native alloy of nickel and iron with other
metals occurs in the meteoric masses which are occasionally

found.   Steel containing a considerable percentage of nickel is now regularly made.

Cobalt also readily alloys itself with iron, producing similar alloys to those last described ; small quantities do not produce any material alteration in the physical or working qualities of the iron or steel.

Lead does not appear to unite with iron when the two are melted together, and no satisfactory alloy has been described of these metals.

Aluminium yields, with iron, alloys of various composition, and the alloy known as ferro-aluminium is used to some extent in steel making.

Silver does not appear to unite with iron when melted along with it, for when the mixture cools the silver is found to have separated throughout the mass, and not to have produced any homogeneous alloy.

Gold alloys itself readily with iron, upon simple fusion together of the two metals, the alloy being harder than malleable iron.

Platinum alloys with iron without difficulty, the melting-point of the alloy being below that of steel.   Steel containing 1 per cent. of platinum is tough, fine-grained, tenacious, and ductile.   Similar alloys are also obtainable by the substitution of small quantities of the rarer metals palladium and rhodium.

CHAPTER V:

CAST-IRON OR PIG-IRON:

PIG-IRON is the product formed by treating iron ores with fuel and fluxes in the blast furnace. It is an impure iron containing carbon, silicon, sulphur, phosphorus, manganese, and often with smaller quantities of other metals, such as arsenic, titanium, copper, chromium, etc.

Owing to the high temperature of the blast furnace the iron always takes up nearly the maximum amount of carbon and the other constituents, which are of course derived from the ore, fluxes, or fuels employed in the smelting operation. Of these, carbon and silicon may be regarded as being essentials, since they are always present, and without them the iron would not be pig iron, whilst the other elements present in smaller quantities in ordinary pig iron are not essential.

Pig irons vary very widely in composition and in properties. Indeed, the only points in common are the method of production and the invariable presence of carbon and silicon. Apart from these they might be considered as different metals, so much do they differ in properties.

Pig-iron is thus essentially iron containing from 2 to 4·5 per cent. of carbon, existing partly in chemical combination with the iron, and partially as mechanically-distributed uncombined or graphitic carbon, and on the relative proportion of the two forms of carbon depends the most striking difference between the varieties. When a pig-iron containing most of its carbon in the form of graphite is broken, the fracture is dark grey, or nearly black, in colour, and shows distinct flakes of graphite and is called a grey iron ; on the other hand, if most of the carbon is present in combination, the fracture is silver-white in colour, granular but not largely crystalline, showing no trace of graphite, and the iron is said to be white.

In the greyest iron the carbon is almost wholly uncom-

bined, whilst in the hardest white iron it is almost entirely combined. Upon the relative proportions of the two forms of carbon, modified by the presence, mode of occurrence, and varying proportions of the foreign elements above-mentioned, depend the wide variations in the colour, hardness, strength, fusibility, specific gravity, behaviour when treated with acids, and adaptability of the metal to special purposes; but in all its varieties it differs from malleable-iron and steel by an almost total absence of ductility, in being unforgeable and unweldable; it is also more brittle, not so tough, and is usually harder than malleable-iron. The greyest iron corresponds to the largest proportion of graphitic carbon, and the larger the proportion of graphite the weaker is the metal. The graphite is distributed through the iron in the form of very thin plates, with their long axes nearly at right angles to the surfaces of cooling, so that when the pig is broken the fracture is determined along the cleavage planes of the graphite, which makes the graphite appear more prominent than its percentage would seem to warrant. White iron corresponds to the condition of the largest proportion of combined carbon. Between the two extremes, the gradation is more or less gradual, although at a certain intermediate stage the metal exhibits white iron dispersed through a matrix of grey, such metal being described as mottled pig-iron.

Pig-iron, in cooling from a state of fusion, crystallises in octahedral crystals; the dominating form of crystals being the octahedron or the cube, but crystals are difficult to obtain. The specific gravity of pig-iron varies from about 7·2 in grey to about 7·5 in white iron.

Pig-iron is usually found in commerce in the form of oblong blocks or pigs of ⊔ section, about 3 ft. long, and weighing about 1 cwt., the metal being run direct from the blast furnace into open grooves or channels of the above section, formed in the sand of the pig-bed in front of the furnace.

The various qualities of pig-iron as delivered from the blast furnace are distinguished by marks or numbers indicating the grade or quality, and the purposes to which they are applicable. The pig-iron produced from the same ores is broadly described as grey, mottled, or white iron, according

to the appearance of the fracture, but each variety is
again further classified. Thus in the Cleveland, in Sootland,
and in the Midlands district, according to the colour, strength,
and general appearance of the fracture of a freshly broken
pig, foundry pig is described as being of No. 1, No. 2, No. 3,
No. 4, or No. 4 forge ; whilst in Lancashire the No. 4 forge, or
strong forge of the Cleveland district, is represented by V,
whilst the other numbers or grades are designated by the
same series of numbers in the two districts.   In America
Nos. 1 to 10 are used, No. 1 being the greyest, but three

Fig. 13.—Pig-iron No. 1 Fracture.

highly siliceous or silver grey irons, which are not included
in the classification used in this country, are inserted between
our numbers 3 and 4.   In all cases No. 1 mottled and white
are the same, the difference being in the arrangement of the
intermediate numbers or in the introduction of other grades.

   The grading is based entirely upon the appearance of the
fractures when the pigs are broken.   Though this method of
classifying pig-irons is in general use, it is most unsatisfactory :
(1) because there is no absolute standard to which each grade
must conform, and (2) because the fracture may depend on
other conditions beside the actual chemical composition of

the metal. At present no perfectly satisfactory substitute has been found. The following are the properties usually ascribed to the various grades.

No. 1, No. 2, and No. 3 grades of pig-iron are especially applicable to foundry purposes and for special casting;

Fig. 14.—Hæmatite Iron No. 1 Micro Section.

Fig. 15.—Cleveland Iron No. 1 Micro Section.

No. 4 is available for foundry purposes, especially when mixed with softer irons; No. 4 Forge or V is only applicable for conversion into malleable-iron in the puddling furnace. The market value of the several grades thus decreases from No. 1 to No. 4, the higher number being the cheaper iron.

No. 1 pig-iron is the darkest grey; its fracture is largely crystalline and presents numerous graphitic planes (Fig. 13). It contains the maximum proportion of graphite, is the most readily fusible, is deficient in hardness and strength, and the pig breaks with a dull leaden sound, indicating but little

Fig. 16.—Pig-iron No. 2 Fracture.

tenacity. This metal is used for the finest and most accurate castings, where great strength is not required. The surface of the molten metal is dark and sluggish-looking, not giving off sparks and splashes, and as it cools in mass a thick scum or dross separates on its surface.

Under the microscope No. 1 iron is seen to consist of a ground mass of ferrite (in this case silicon ferrite), scattered through which are large plates of graphite and very small particles of pearlite; the latter, however, can only be made out under high magnification. If the iron is a foundry pig, and therefore contains a considerable quantity of phosphorus, the phosphide eutectic will also be seen as the portion which solidified last.

No. 2 pig-iron is lighter in colour than No. 1 ; usually the surface of the pig is smoother, it is finer in grain, more regular in fracture, and is a little harder and stronger than No. 1, but is not quite so fluid when in the molten state. The surface of the molten metal is of a clearer red than No. 1, and it flows from the founders' ladle in large sheets, splashing a little, and its surface exhibits as it cools a series of lines or figures ever varying as though the surface were in circulation, such appearances continuing until the metal becomes pasty. A scum rises to the surface of molten No. 2 pig-iron, but not to the same extent as in No. 1.

Fig. 17.—Pig-iron No. 3 Fracture.

No. 3 pig-iron is still lighter in colour, the crystals are much smaller, the fracture smoother, more compact and dense-looking ; it is also much harder, stronger, and tougher than the lower numbers, and is consequently largely used in conjunction with scrap for the large castings required in structural ironwork, the usual specification test for which is that a bar, 2 in. deep by 1 in. in width, supported upon 3-ft. centres, shall not break with a less weight than 28 cwt. applied at centre ; although some engineers will accept a load of 24 cwt., whilst others specify 32 cwt. as the breaking load ; but this latter is extremely difficult to obtain with

ordinary hot-blast pig-iron. No. 3 pig-iron contains less graphite than No. 1 or No. 2, and has not the same fluidity when melted, whilst the molten metal throws off sparks abundantly as it is poured from the foundry ladle, and its surface is freer from scum than either of the lower numbers, but the surface-figuring spoken of with respect to No. 2 is much less distinctly seen with the metal of No. 3 grade.

No. 4 iron is stronger than those previously described ; it is whiter in colour, more lustrous, has a granular, uneven, and more or less mottled appearance on fracture ; it is not
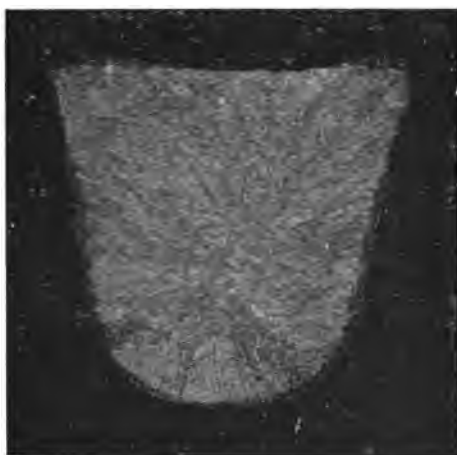
Fig. 18.—White Iron Fracture.

nearly so fluid when melted as the lower numbers, whilst the surface of the molten metal appears hotter, and the metal throws out showers of sparks as it is poured from the casting ladle. It is used only for the heaviest classes of foundry work, and is quite unsuitable for small, light, or ornamental castings.

No. 4 Forge, strong forge-pig or V, approaches to white-ness in colour, being harder and also lighter in colour than the last. This number presents a dull and more flaky appear-ance on fracture, and is only available for conversion into malleable or wrought-iron by the puddling process ; for in

melting it passes, previous to complete fusion, through an intermediate pasty condition particularly favourable for its decarburisation in the puddling furnace, and with less loss of iron than if the metal were in a more perfectly fluid state.

White iron is hard and brittle, and breaks with a white crystalline fracture, showing no flakes of graphite. When melted it yields a pasty liquid which does not flow freely, so that it is no use for foundry work. Under the microscope it is seen to consist of portions of pearlite surrounded by a ground mass of the hard cementite.

Fig. 19.—White Iron Micro Section.

Mottled iron consists of a mass of white iron scattered through which are particles of varying size of grey iron.

Grey iron is more fluid when melted than white iron, but it requires a higher temperature for its fusion ; grey iron melts at a temperature of about 1,600° C. or 1,700° C. (2,912° F. to 3,452° F.), and white iron at a temperature of from 1,400° C. to ‑1,500° C. (2,532° F. to 2,732° F.). White iron contracts in passing from the liquid to the solid state, and it passes through a soft, pasty condition before complete fusion occurs, as also through a similar condition in assuming the solid state after fusion ; and these qualities adapt it for the processes of dry puddling by which it is

converted into malleable-iron, but render it unfit for foundry use. Grey iron, on the other hand, passes during fusion directly from the solid to the fluid state, and *vice versâ*, and it also expands at the moment of its solidification from the fluid state, thus insinuating itself into the finest lines of the moulds in which it is contained. Hence grey pig-iron is in request, more especially for the production of light ornamental and intricate castings, so that it has thus become usual to speak of the softer grades of pig-iron as foundry pig, in

ANALYSES OF

Constituent.	Grey, All-mine Pig.	Bowling No. 1 Grey, Cold-blast. (Abel.)	Hæmatite Pig, No. 1, Grey. (Greenwood.)	Northamptonshire, Hot-blast. (Henry.)	Dutterly, Hot-blast, from Derbyshire Ores.	Kirkless Hall No. 3 Pig-iron.	West Hallam, Derbyshire, No. 3 Foundry. (Whitehouse.)	North Staffordshire, Hot-blast. (Williamson.)
Graphitic Carbon	3·10	} 2·99	3·045	1·150	3·35	3·25	2·60	2·54
Combined Carbon	0·04		0·704	0·554	—	—	—	—
Silicon	2·16	0·97	2·003	1·900	1·27	2·70	1·26	2·71
Sulphur	0·11	0·05	0·008	0·414	0·02	0·08	0·05	0·04
Phosphorus	0·63	0·50	0·037	1·807	1·09	1·73	0·72	1·07
Manganese	0·50	—	0·309	0·395	1·01	2·37	0·45	0·98
Metallic Iron	94·55	—	93·800	93·780	93·26	89·90	94·92	92·66
Calcium	—	—	—	—	—	—	—	—
	101·10	—	99·906	100·000	100·00	100·03	100·00	100·00

contradistinction to the harder and whiter varieties, which are described as forge qualities.

Pig- or cast-iron is decomposed when exposed to the action of sea-water, so that in time it will be left as a soft porous mass, having its original form, and being in some instances spontaneously inflammable after careful drying.

Grey cast-iron, if not too grey, is converted into white iron by sudden cooling, as in the familiar process of chill casting, where by pouring the fluid metal into metallic moulds the heat is rapidly withdrawn from the surface of the casting, which is thus converted into hard white iron, whilst the body of the casting remains grey iron ; the depth and degree of the chilling or whitening depend upon the thickness, etc.,

of the mould and the character of the iron. The flat plates or pigs of Swedish pig-iron commonly present on fracture a white skin, with a grey interior, produced by the Swedish practice of running the pig metal into cast-iron open moulds. In white iron produced by the chilling of grey iron, the carbon in the chilled surface has largely remained in the combined form instead of passing into the graphitic form as in the grey metal. Molten pig-iron is a solution of various substances in liquid iron, and the form these assume in the

PIG-IRON.

Cleveland No. 2 Foundry Hot-blast. (Abel.)	*Bessemer Pig, No. 2, Grey. (Greenwood.)*	*Grey Cinder-pig. (Noad.)*	*No. 4 Forge Hot-blast. (Stock.)*	*Mottled Charcoal Pig. (Rosthorn.)*	*Mottled Pig.*	*White Pig-iron.*	*Spiegeleisen. (Tookey.)*	*Styrian White Pig.*	*Joachimsthal White Pig-iron.*	*Cleveland No. 1. (Pattinson.)*	*Cleveland No. 2. (Pattinson.)*
3·44	2·579	2·80	2 719	2·02	1·99	0·87	5·04	2·93	3·60	2·83	2·45
1·13	1·175	1·85	1·222	1·43	2·78	2·46	0·41	0·307	0·66	0·48	0·26
0·08	1·758	0·14	1·608	0·92	0·66	1·12	0·08	0·018	0·021	2·31	1·57
1·24	0·014	1·66	0·031	0·04	trace	2·52	0·16	0·021	0·52	0·04	trace
0·43	0·038	—	0·016	0·04	1·23	0·91	7·57	0·724	0·531	0·30	1·00
93·73	0·130	93·55	0·021	2·02	—	2·72	86·74	96·000	95·136	0·57	0·93
—	94·304	—	94·309	94·08	93·29	—	—	—	—	93·03	94·64
			0·074								
100·00	99·998	100·00	100·000	100·55	100·00	—	100·00	100·000	100·468	99·56	101·15

solidified metal depends partly upon the manner of cooling, both before and after solidification ; since even after solidification, but whilst the mass is still at a red heat, it is possible to alter the nature of the metal, as by tempering, cementation, or sudden cooling.

When a mass of very grey iron is allowed to cool slowly from a state of fusion, as in the case of the molten metal standing in a foundry ladle, a scum or kish rises to the surface, which consists largely of graphitic matter ; hence fluid cast-iron is capable of holding a larger amount of carbon in solution than metal cooled more slowly from a state of fusion can retain. The scum or kish may contain as much as 0·22 per cent. of sulphur and 5·19 per cent. of manganese, the relative

proportions of these elements in the pig-iron being at the same time 0·05 and 2·62 per cent. respectively.

Hot-blast pig-iron, owing to the higher temperature of the furnace during its production, is usually more siliceous than cold-blast pig, smelted from the same or a similar mixture of ores, and from the same cause also grey pig-iron is more siliceous than white iron.

Pig-iron is soluble in acids, but leaves an insoluble residue. of silicon, graphite, etc. The whole of the graphite is in the residue, but the combined carbon escapes with the evolved hydrogen.

The strength of cast-iron varies with the chemical composition, the mode of production whether by hot-blast or cold-blast, mode of treatment after leaving the blast furnace, etc.; thus cold-blast iron is stronger than hot-blast from the same ores. Annealing diminishes the strength of cast-iron; the presence of silicon beyond certain limits impairs its tensile strength, and any considerable amount of phosphorus weakens it considerably. Repeated re-melting was considered to improve the quality and strength of cast-iron, but whether this is so or not depends on the composition of the iron. Grey cast-iron is usually rendered stronger after each re-melting for a certain number of meltings, after which it becomes weaker by continued re-melting.

The tensile strength of pig-iron varies between 5 and 14 tons per sq. in. of section, but the average of good cast-iron is about 8 tons. The transverse and torsional strength of pig-iron is low, each varying between 1·5 and 4·5 ton per sq. in.; and it has an average shearing strength of 12 tons per sq. in.; whilst its crushing strength ranges from 35 to 90 tons per sq. in. of section, the average strength of good sound specimens being from 50 to 60 tons per sq. in. Owing to the high strength of cast-iron under a crushing or compressive stress, this metal is usually employed for columns, struts, etc., and but rarely in structural members subject to torsional, tensional, or transverse stresses. Cast-iron is thus stronger than wrought-iron in compression, but much weaker in tension; and within a limited range of stress it is tougher, or permits of a greater degree of deformation than wrought-iron, but its range of deformation is not large; hence it is

not so safe as wrought-iron when subject to suddenly applied stresses.

Influence of Various Constituents on Pig-iron.—Since pig-iron must owe its characters to the various constituents which are present in it, it becomes essential to study the influence of each of these separately.

Carbon is, of course, the essential constituent, and it, as pointed out in the last chapter, can exist in two forms—as graphite and as combined carbon.

Graphite is simply an intermixed constituent, and therefore can only influence the quality of the iron as any other intermixed substance would do. Graphite occurs in flakes of varying size, and as these flakes have a very perfect cleavage they have little strength, and the presence of them must necessarily weaken the iron. For this reason very grey irons are always weak. Not only is the actual amount of graphite of importance, but the size of the flakes also has an influence. A very grey iron, with large flakes of graphite, will be said to be an "open" iron, and will be weak; whilst an iron with the same percentage of graphite, but in which the flakes are much smaller, will be a "close" iron, and will be considerably stronger. The terms "open" and "close" relate to the appearance of the fracture of the pig, and depend more on the size of the graphite flakes than on the actual amount of graphite present.

Combined carbon is of much more importance. It is present as the carbide Fe_3C, always united with some of the ferrite so as to form pearlite. As the carbide is very hard and strong, its presence increases the hardness and strength of the metal. Indeed, the strength of pig largely depends on the amount of combined carbon present. Turner gives for extra soft iron, 0·08 per cent.; soft iron, 0·15 per cent.; maximum tensile strength, 0·47 per cent.; maximum transverse strength, 0·70 per cent.; maximum crushing strength, over 1·00 per cent.

Silicon is always present in pig-iron. From its similarity to carbon it was once thought that it might exist in two forms —a graphitic and a combined form—but all attempts to obtain a graphitic form of silicon have failed, and it may safely be said that silicon in iron always exists in the combined form. It is probably present as a silicide, but this dissolves in the

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excess of iron, so that the presence of silicon is not detectable under the microscope ; and when silicon is present the ferrite —that is, the iron ground mass, is often called silicon-ferrite.

Silicon has a two-fold influence on iron. Its direct influence is to harden the iron, but to a much less extent than carbon. Its indirect action is far more important. It has a tendency to prevent carbon remaining in the combined condition, and to throw it out in the form of graphite. Silicon, when added to iron, therefore becomes a softening agent. By its own direct action it no doubt hardens the metal, but by its indirect action of throwing the carbon out of combination it softens it far more than it hardens it directly.

Silicon thus becomes the dominating element in pig iron, the forms in which the carbon exists largely depending on the quantity of silicon which is present. It is absolutely necessary to understand this dual action of silicon, if the variations in the character of pig iron by modifications in treatment are to be understood.

The influence of silicon on pig-iron, or rather on iron containing carbon, has been investigated by Professor Turner, of Birmingham, and his classical research is the basis of all that has been done since. He found that for any important property of iron to exist in the highest degree the presence of a certain quantity of silicon was essential, the amount varying with the property under investigation.

The following table sums up the results of his work, and shows the amount of silicon necessary :—

For Maximum Hardness	. . .	Under 0·80 per cent.
„	Crushing Strength . .	About 0·80 „
„	Modulus of Elasticity .	„ 1·00 „
„	Density in Mass . .	„ 1·00 „
„	Tensile Strength . .	„ 1·80 „
„	Softness and General Working Properties .	„ 2·50 „
For Lowest Combined Carbon . .		Under 5·00 „

In all cases the property under investigation fell off rapidly from the maximum as the amount of silicon was exceeded. The curves in Fig. 20 show graphically Professor Turner's results for crushing strength, tensile strength, and modulus of elasticity.

Sulphur is present in pig-iron generally to the extent of

a few hundredths per cent. only ; thus the pig-iron smelted from clay ironstones without any admixture of cinder usually contains from 0·02 to 0·1 per cent. of sulphur ; but in smelting for common forge-pig in South Wales, cinder is sometimes added to the furnace charge, and the sulphur may reach as much as 0·7 per cent. The percentage of sulphur in pig-iron generally increases with the number or grade
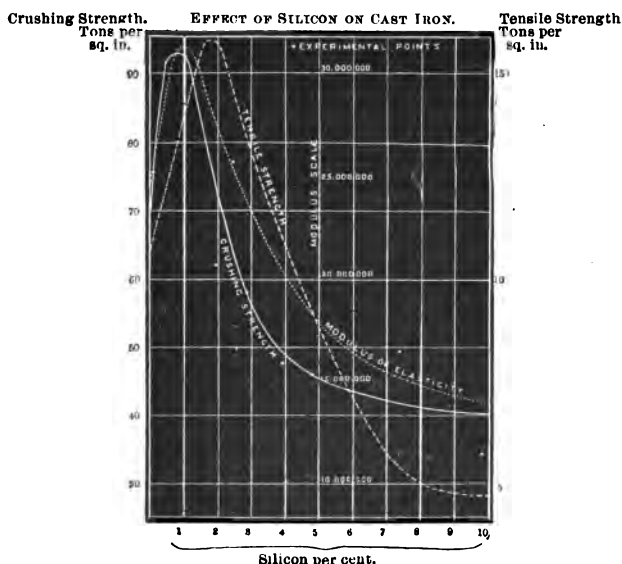
Fig. 20.—Effect of Silicon on the Crushing Strength of Cast-iron shown by Graphic Diagram.

of the metal. Pig-iron containing upwards of 0·03 per cent. of sulphur is unsuitable for conversion into steel, because the sulphur is not removed in the process, and therefore produces a steel that is red-short. For foundry purposes small percentages of sulphur tend to harden the metal and increase its tensile strength ; hence the practice in Sweden of occasionally adding small quanti.ies of pyrites to the furnace charge when melting pig-iron for ordnance purposes. Under ordinary circumstances, if the silicon be high, the sulphur will be low.

The effect of sulphur upon pig iron is exactly the opposite of that of silicon ; that is, it tends to throw the carbon into the combined condition, and thus to harden and whiten the metal. A small quantity of sulphur can thus neutralise the action of a considerable quantity of silicon, and white irons fairly high in silicon can be obtained. When the quantity of sulphur is over a few, tenths per cent. the sulphide may separate on cooling. Good foundry iron should never contain more than ·15 per cent. of sulphur.

Phosphorus is always present in pig-iron. It tends to make the fracture more largely crystalline, and if present in large quantity it reduces the tensile strength of the iron ; but in proportions up to 0·5 or 0·75 per cent. it is doubtful whether it has any decided influence upon the tensile strength of cast-iron, whilst 1·5 per cent. of phosphorus produces a pig-iron which is decidedly weak.

Phosphorus makes the iron more fluid, and therefore facilitates the making of good castings. For foundry purposes iron with a considerable percentage of phosphorus is usually selected. Good Scottish foundry irons contain from 0·7 to 1 per cent. of phosphorus, and Middlesbrough pig 1·25 per cent. or more ; but since the phosphorus is not removed in steel making, iron required for that purpose should not contain more than about ·05 per cent. Phosphorus, as explained above, forms a definite phosphide which dissolves, to a certain extent, in the metal ; but it is much less soluble, in the solid condition, in pig-iron containing carbon and silicon than in pure iron. As the iron solidifies, the fusible liquid eutectic, which contains about 10 per cent. of phosphorus and is much more complex than in the case of pure iron, is separated and remains fluid to the last, and even a few tenths per cent. of phosphorus can be detected by the appearance of the metal under the microscope. If the quantity of phosphorus be large, the eutectic may separate in distinct globules of considerable size, and when the pig is broken these may fall out, leaving spherical cavities. If the iron cools very slowly, the contraction may force the still liquid phosphide eutectic to the surface, where it will appear as metallic globules.

The whole of the phosphorus in the charge passes into the metal, so that the only way to prepare an iron low in

phosphorus is to use material which contains little of that element.

Titanium frequently occurs in grey pig-iron, but in white iron it has always escaped detection, even when ores containing it have been added to the furnace charge, owing to the very high temperature required for its reduction.

Copper has been found in pig-iron from various places. Small proportions up to 0·2 per cent. of copper in pig-iron are said not to affect its quality for foundry purposes or for steel making.

Tin renders pig-iron hard and more readily fusible ; but
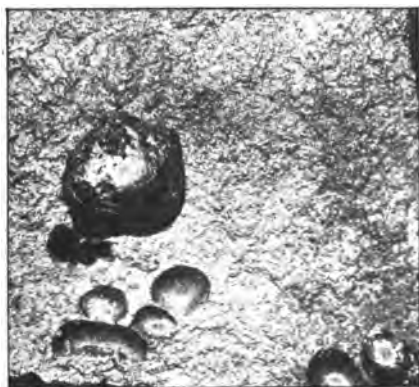
Fig. 21.—Globules of Phosphide Eutectic in Pig-iron.

stanniferous pig, after treatment in the puddling furnace, yields a malleable iron which is exceedingly cold-short and inferior in quality.

Manganese is always present in pig-iron, and if present in large quantity tends to render it white and brittle. When contained in an ore it helps to eliminate the sulphur from the resultant pig-iron. In ordinary circumstances about half the manganese in the charge passes into the iron, so that some manganese always passes into the slag. Spiegeleisen is a highly manganiferous pig-iron, containing from 6 to 20 or 30 per cent. of manganese, and possessing well-marked physical qualities ; thus it is very hard, and its

fracture presents large cleavage planes, which are due to fracture taking place along planes of carbide of iron.

Manganese irons containing 80 per cent. or more of manganese are now regularly made under the name of ferro-manganese; these present a granular crystalline fracture void of any cleavage or lamellar structure, and of a bronze colour.

Irons containing a large quantity of manganese can take up more carbon than ordinary pig-iron, ferro-manganese often containing up to 7 per cent. This is present either as a carbide of manganese or as a double carbide of iron and manganese. A large quantity of silicon may also be present, the alloy then being known as silicon ferro-manganese.

Grade of Pig-iron.—The grade of pig-iron, as determined by the fracture as described above depends on the appearance of the fracture, and this in its turn depends on the amount of graphite which is visible, and this again depends on the other constituents present and also the rate of cooling and other conditions.

As already remarked, silicon tends to throw the carbon into the graphitic condition, whilst sulphur has exactly the opposite effect. Other constituents have less influence, or act indirectly : manganese by tending to the removal of sulphur, and phosphorus by tending to retard solidification, help to make the iron grey Silicon is, on the whole, the most important element in this connection, and it has been suggested that irons should be graded according to the percentage of silicon present, as determined by analysis, instead of by the appearance of the fracture. The following analyses show the sort of relationship that should exist :—

HÆMATITE PIG (C. H. RIDSDALE).

				1	2	3	Forge
Graphitic Carbon	.	.	.	3·52	3·40	3·10	2·30
Combined ,,	.	.	.	·18	·25	·36	·79
Silicon	.	.	.	2·85	2·60	2·08	1·35

FOREST OF DEAN HÆMATITE (PATTINSON & STEAD).

		1	2	3	4	Mottled	White
Graphitic Carbon	.	3·897	3·660	3·020	2·865	2·375	·825
Combined ,,	.	·395	·570	1·070	1·065	1·316	2·387
Silicon	.	1·073	·975	·587	·728	·401	·305

These figures show the way in which the combined carbon rises as the silicon falls. It is only the combined carbon that

need be considered, since, if this be fixed, the amount of graphite will vary with percentage of total carbon. This method of grading is now being largely used, but to make it satisfactory, the amount of sulphur and manganese must also be considered, and this would make the matter much more complex.

It must be remembered that grading by the appearance of the fracture is very uncertain, and leaves far too much to the personal equation. If an iron be cooled slowly there will be more time for the carbon to separate, and the iron will tend in the direction of greyness, whilst if the cooling be rapid, the separation of the graphite may be retarded or prevented, thus modifying the iron in the direction of whiteness. When iron is cast, as it now sometimes is, in iron, instead of in sand moulds, the outer surface becomes converted into white iron, whilst the mass of the pig is far less graphitic than it would have been if the cooling had been slower. Grading by the appearance of the fracture is therefore only of value if the iron is cast always under the same conditions.

If a white iron be kept for a considerable time at a temperature a little below its melting point, the carbon is almost completely separated.

Varieties of Pig-iron.—There are many varieties of pig-iron.

Foundry pig is iron suitable for use in the foundry. It may be of any grade, and therefore may contain varying quantities of silicon and combined carbon, but it will always contain from ·7 to 1·25 per cent. of phosphorus.

Bessemer or hæmatite pig is pig-iron suitable for conversion into steel by the Bessemer or open-hearth steel processes. It must not contain more than ·06 per cent. phosphorus or ·05 per cent. sulphur. For the Bessemer process about 2·5 per cent. of silicon should be present, but for the open-hearth process the amount of silicon is unimportant. It is called Bessemer pig because it was made for use in the Bessemer process of making steel, and hæmatite pig because it is usually made from hæmatite ore.

Basic pig is pig iron made for the basic Bessemer or Thomas Gilchrist process of steel-making. It is, of course, not "basic" in the chemical sense. It should contain from

' 3 to 4 per cent. of phosphorus, and the silicon should be as low as possible, never more than 1 per cent., so that the iron is usually white.

All mine pig is pig-iron, made, in the Midlands, from iron ore without the admixture of slag or cinder from the puddling furnaces. In most districts all the pig-iron made is of this character, and the term is not used.

Cinder pig is pig-iron made from a charge consisting almost entirely of puddlers or other slag or cinder. It is usually very high in phosphorus, often spongy, and porous in texture. The term is only used in the Midlands.

Glazed pig is a pig-iron containing a large percentage of silicon, made accidentally, and so called from the bright fracture. In the United States such iron is called silvery or silver-grey iron.

A geographical classification is sometimes used, thus : Scotch pig is made in Scotland, Middlesbrough (or Cleveland) pig is made in Middlesbrough, and so on; in Scotland the pigs are further marked with the name of the works where they are made, and some works have such a high reputation that their brands of iron fetch a much higher price than others.

For instance, on May 11th, 1906, prices were :—

	s.	d.		
Cleveland No. 1	51	9	per ton.	
,, No. 3	50	3	,,	(F.O.B. Cleveland).
,, White	48	6	,,	
Scotland—				
Gartsherrie No. 1	65	0	,,	
Coltness ,,	74	0	,,	
Summerlee ,,	68	6	,,	
Langloan ,,	67	6	,,	
Clyde ,,	64	6	,,	(F.O.B. Glasgow).
Carnbroe ,,	62	0	,,	
Glengarnock ,,	66	0	,,	
Eglinton ,,	60	6	,,	(F.O B. Ardrossan).
Shotts ,,	68	0	,,	(F.O.B. Lent).
Lincolnshire No. 3	55	6	,,	
Derbyshire ,,	58	6	,,	
Staffordshire	53	0	,,	
Lancashire	54	0	,,	

It will thus be seen that the prices vary very much. No. 1 is always the most expensive, and the prices fall at about 2s. 6d. per ton for each number. Of course, the purchaser has

to consider the cost of carriage to the place where he will need to use the metal from the port or station at which it is delivered f.o.b. (free on board) at the price quoted. In the case of Cleveland iron, no particular maker's iron fetches a higher price than others, and the buyer does not usually ask for any particular make, but simply for good makers' brands (G. M. B.).

Production of Pig-iron.—The amount of pig-iron made in the world in 1905 was :—

United Kingdom	9,592,737 tons.
United States	22,992,380 „
Germany	10,066,553 „

Pig-iron Alloys.—A large number of alloys are now made which may be classed with pig-irons because they are made in the blast furnace by exactly the same processes and contain the same impurities. Some of these have already been mentioned.

Manganese Alloys :—

Spiegeleisen, containing up to 30 per cent. manganese.

Ferro-manganese, containing up to 85 per cent. manganese.

Silicon Alloys :—

Ferro-silicon, containing up to 15 per cent. silicon.

Silicon ferro-manganese, containing up to 70 per cent. manganese and a large quantity of silicon.

Chrome Alloys :—

Ferro-chrome, containing up to 65 per cent. of chromium.

Many other alloys are made by melting in crucibles.

CHAPTER VI.

PREPARATION OF THE ORES.

THE production of pig-iron from the various ores of iron comprises two stages—the preparation and the smelting of the iron ores.

Owing to the comparatively small value of iron, the ores are not usually submitted to any complicated or expensive mechanical treatment for the separation of the gangue or earthy portions, before calcination or smelting, except in cases where magnetic separation can be profitably used.

The preparatory treatment of the ore may include *a*, Mechanical preparation of the ores; *b*, Weathering of certain classes of ores; *c*, Roasting, or calcination of the ore; *d*, Magnetic concentration.

In England iron ore is sent to the kiln or direct to the furnace in lumps of irregular size, often mixed with a considerable amount of small material, as it is delivered at the works from the mine. At one time it was customary in the Cleveland district to break the ore into lumps approximately of from 4 in. to 6 in. cube; and in the hæmatite districts, where the furnaces were smaller, into 2-in. cubes resembling road-metalling, whilst for the still smaller furnaces employed in Sweden the pieces were only about 1-in. cube, but this sizing is not necessary for the modern large furnaces. In some districts the hard ores are broken by stone crushers, such as the " Blake," in which the ore is broken by a strong oscillating jaw, moving to and from a corresponding hard fixed face; or in the case of calcined ores by passing between hard cast-iron rollers.

Weathering.—Weathering of iron ores is only necessary for such ores as contain much pyrites or shale; in which case, instead of directly calcining, or in exceptional cases after

calcination, the ores are exposed in heaps to the action of the atmosphere. Under the action of air and moisture, the sulphur is oxidised and produces soluble sulphates, which are dissolved out by the rain. This method is not applicable to the treatment of calcareous ores, since the soluble ferrous and cuprous sulphates formed by the oxidation would be decomposed by the lime, with the formation of a sparingly soluble calcium sulphate, which largely escapes solution ; and thus the copper and sulphur would both remain in the ore, although in different states of combination from those in which they occurred in the original ores. Also such calcareous ores cannot be sub-jected to any prolonged weathering after calcination, other-wise the ore would break up and fall into powder, owing to the slacking of the lime during the lixiviation for the solution of the soluble sulphates, and so be unfit for introduction into the blast furnace.

Suitable ores may be weathered for three or four months ; and in exceptional cases, as with the pyritous siliceous hæmatites of Germany, the weathering after roasting extends over one, two, or three years, with occasional lixiviation or washings during the whole period. Certain nodular ar-gillaceous ironstones which are accompanied by shale suffer oxidation on exposure to the atmosphere for a short time, whereby the shale, which is not readily separated from the ore · as it is first received from the mines, becomes easily separable. Again, certain spathose ores are converted by a limited exposure to the weather into brown hæmatite ; but in all these special cases it becomes necessary not to carry the operation of weathering too far, otherwise the ore falls to powder and becomes unfitted for charging into the blast furnace.

Weathering is now completely abandoned except in a few outlying districts where the output is very small. The space required for the weathering of the large quantities of ore required for a modern blast furnace would alone render the process impracticable.

Calcination.—The calcination or roasting of iron-ores expels water, carbon-dioxide (CO_2), sulphur, and substances which are volatile under the influence of heat, or the combined action of heat and atmospheric air. The process leaves the ore in a more or less porous condition, more readily permeated

and acted upon by the reducing gases of the blast furnace. The partial oxidation which occurs during calcination converts the ferrous compounds—such as are contained in spathic ores, and whch would readily combine with and form fusible compounds with silica in the blast furnace—into ferric oxide, which does not so readily combine with silica.

The changes produced by calcination are comparatively simple. They are partially produced by the action of the heat, and partially by the oxidising action of the air. The iron will be present in the ore, as ferric oxide (Fe_2O_3), ferric hydrate ($2Fe_2O_3, 3H_2O$), black oxide of iron (Fe_3O_4), ferrous carbonate ($FeCO_3$), and perhaps a small quantity of pyrites (FeS_2).

Ferric oxide will be unchanged, except that if the temperature be high it may be partially converted into the black oxide, this change taking place much more readily in the presence of reducing agents, and in some cases reduction may even go further, ferrous oxide being produced ; ferric hydrate will be converted into the oxide by expulsion of water. Ferrous carbonate is decomposed, ferric oxide being left thus : $2FeCO_3 = Fe_2O_3 + CO + CO_2$, one part of the carbonate giving ·69 parts of the oxide. Sometimes in the analysis of an ore ferrous carbonate is stated as FeO and CO_2; in that case it may be considered that the FeO is oxidised to Fe_2O_3, thus $2FeO_3 + O = Fe_2O_3$, and the carbon-dioxide is expelled. Each 1 part of ferrous oxide will give 1·11 parts of ferric oxide.

The pyrites is oxidised, yielding ferric oxide and gaseous sulphur dioxide : $Fe_2S_2 + 11O = Fe_2O_3 + 4SO_2$, one part of pyrites giving ·67 parts of the oxide. In either case the ferric oxide may be subsequently converted into the black oxide. It will be seen, therefore, that whatever the form in which the iron exists in the ore, it will be in the condition of oxide after calcination.

Manganese will be present usually as carbonate, which will be decomposed thus : $3MnCO_3 = Mn_3O_4 + 2CO_2 + CO$, 1 part of the carbonate giving ·66 of manganic oxide. This may also be written as if the carbonate were made up of MnO and CO_2, in which case the carbon dioxide will be expelled and the manganous oxide converted into manganic

oxide : $3MnO + O = Mn_3O_4$, 1 part of manganous oxide giving 1·075 parts of manganic oxide.

Lime and other carbonates, if present, will be decomposed, the metallic oxide being left and carbon dioxide evolved thus : $CaCO_3 = CaO + CO_2$, 1 part of calcium carbonate giving ·56 parts of lime. Water will, of course, be expelled, and organic matter will be partly volatilised and partly oxidised.

As a result of these changes, there will be considerable loss of weight, and the resulting calcined ore will necessarily be richer in iron than the raw material.

An example will make this clear. Assume an ore to contain :—

Ferrous Carbonate	60	per cent.
Manganous Carbonate	2	„
Calcium Carbonate	8	„
Silica, Alumina, etc.	10	„
Pyrites	1	„
Organic Matter	10	„
Water	9	„
	100	„

Required to find :—

(1) The loss on calcination.

(2) The percentage of iron in the raw and in the calcined ore.

To find the loss on calcination, the first step will be to find what will be the weight of 100 lb. of raw ore after calcination, which can be easily obtained from the data already given.

Ferric oxide from Carbonate	$60 \times ·69 =$	41·40
„ „ „ „	$2 \times ·66 =$	1·32
Manganic oxide from Pyrites	$1 \times ·67 =$	·67
Lime	$8 \times ·56 =$	4·48
Silica, etc. (unchanged)	$=$	10·00
Weight after calcination		57·87

That is, 100 lb. of the raw ore will give 57·9 lb. of the calcined ore, or the loss will be 42·1 per cent.

The composition of the ore might have been written :—

Ferrous oxide	37·20
Manganous oxide	1·23
Lime	4·48
Pyrites	1·00
Carbon dioxide	27·08
Silica, etc.	10
Organic Matter	10
Water	9
	99·99

Using this analysis the figures will work out :—

Ferric oxide from Carbonate . . $37\cdot2 \times 1\cdot11 = 41\cdot3$

„   „   „ Pyrites . . . $1\cdot00 \times \cdot67 = \cdot67$

Manganic Oxide . . . $1\cdot23 \times 1\cdot07 = 1\cdot3$

the other figures, of course, working out the same as above.
The percentage of iron in the ore can be readily obtained.

Ferrous carbonate contains	48·3	per cent.	iron.
Ferrous oxide	„	77·8	„ „
Ferric oxide	„	70·0	„ „
Pyrites	„	46·7	„ „

So that the percentage of iron will be $(60 \times \cdot483) + (1 \times \cdot467)$ $= 29\cdot45$, calculated from the analysis written according to the first method, and $(37\cdot3 \times \cdot778) + (1 \times \cdot467) = 29\cdot48$ if it be written by the second method.

The percentage of manganese can be similarly calculated, using the factors given on p. 248.

Since 100 parts of the raw ore give only 57·9 parts of the calcined ore, the percentage of iron will be :

$$(41\cdot4 + \cdot67) = \frac{42\cdot07 \times \cdot7 \times 100}{57\cdot9} = 50\cdot8 \text{ per cent.}$$

Forge- and mill-cinder, which are essentially ferrous silicates, when used as part of a blast furnace charge, is usually roasted in an oxidising atmosphere, which decomposes it, separating the iron in the form of ferric and magnetic oxides, and leaving the silica in its free condition.

The loss of weight during the process of calcination varies with different ores, for, whilst the Blackband bituminous iron-ores of Scotland lose by roasting in some cases as much as 50 per cent. of their weight, the Welsh argillaceous ores lose from 25 to 30 per cent., or an average of about 27 per

cent. The brown hæmatites lose 12 to 14 per cent., and the red hæmatites only about 6 per cent., of their weight, this loss being due to the expulsion of moisture. The loss of weight during calcination is far greater than the shrinkage of bulk, the calcined ore being left in a porous condition suitable for smelting.

The following analyses of Cleveland ore before and after calcination will give an idea of the changes produced :—

ANALYSES OF CLEVELAND STONE.

	A	B
Ferric oxide (Fe_2O_3)	2·60	66·25
Ferrous oxide (FeO)	38·06	—
Manganous oxide (MnO)	0·74	—
Manganic oxide (Mn_3O_4)	—	0·65
Alumina (Al_2O_3)	5·92	7·72
Lime (CaO)	7·77	6·46
Magnesia (MgO)	4·16	4·78
Potash (K_2O)	trace	0·02
Carbonic anhydride (CO_2)	22·00	—
Water (H_2O)	4·45	—
Silica (SiO_2)	10·36	11 87
Sulphur (S)	0·14	—
Phosphoric anhydride (P_2O_5)	1·07	1·13
Sulphuric „ (SO_3)	—	0·90
	97·27	99·78
Metallic iron (per cent.)	30·69	46·37

A.—Cleveland ore or stone, uncalcined. B.—Cleveland stone, after calcination.

The calcined ore may be either red or black. If it is free from organic matter, and the temperature is not too high, it will be red ; but if the temperature has been very high the red oxide may be converted into black oxide. This change takes place much more readily in presence of organic matter, so that calcined blackband ores are usually black in colour. If the temperature is too high the reduction may go on still further, ferrous oxide beng produced ; and this may com-bine with the silica present, forming fusible ferrous silicates, which will soften or melt and frit the material together so that the calcined ore will be dense and non-porous, and in some cases even the lumps of ore may be cemented into a solid mass.

As the calcined ore is lighter than the uncalcined ore, calcination is usually carried out at the mine to reduce the cost of carriage.

Carbonate ores are always calcined. Brown hæmatites may be calcined or used raw, but it is always advisable to calcine them so as to expel the large amount of moisture which is present. Red and black ores are never calcined, except in the case of red ores to be treated by magnetic separation.

Iron ores are calcined in clamps or open heaps, between closed walls, or in variously designed kilns, the temperature being very carefully regulated so that the ores may not be softened, partially fused, or clotted together into compact masses which would be impervious to the ascending gases in the subsequent smelting operation. With such ores as the blackbands, containing much carbonaceous matter, the temperature should not rise sufficiently high to effect a partial reduction of the metal in the ore.

Calcination in Heaps.—This process, as carried on in South Wales, Staffordshire, etc., consists in placing upon a piece of level ground a bed of coal several inches thick, and then building up ore and fuel in alternate layers to form a pile 4 ft. or 5 ft. high. In the Hartz districts the ground layer is a bed of slag, upon which is placed a layer of iron ore, and then alternate layers of fuel and ore, until the whole forms a truncated pyramid about 9 ft. high, with a base measuring about 60 ft. square. In both the English and Continental methods, the fire is lighted at the base of the pile; and, as the process advances, any parts where the combustion is proceeding too rapidly, or where the calcination is too active, are damped down with small ore. In the Hartz the ores to be treated are calcareous, and the process has a duration of from eight to fourteen days; and for the calcination of each cubic foot of such ores about one-third of a cubic foot of small coal is consumed. Blackband ores often contain from 25 to 30 per cent. of combustible matter, and these or such others as contain much bituminous matter are usually roasted without any further addition of fuel or carbonaceous material.

Ores containing much carbonaceous matter, sulphur, or other combustible substances, are treated in longer but narrower heaps, rarely exceeding about 3 ft. in height; these

heaps do not attain to so high a temperature as the larger heaps, and thus the ore is not so liable to become fused together. This class of ore must be calcined in larger pieces than is the case with argillaceous and other ores free from combustible matter. Westphalia ores, which are less rich in carbonaceous matter, are usually treated in heaps of from 20 ft. to 30 ft. wide, from 15 ft. to 20 ft. high, and of various lengths, the period of calcination being from two to three months.

Devices for regulating the heat throughout the mass include modifying the size of the pile, as already noted; and building the larger pieces of ore so as to form draught-holes communicating with the interior of the heap, and placing around these draught-holes the smaller ore, whereby, when the pile is ignited, the direction of the flame and heat can be controlled by damping down the surface or opening out these draught-holes as required. In the Westphalian works draught-holes are formed between the sides of the pile and other passages in the interior of the pile; these passages are first filled with wood, and the pile is constructed by placing the larger lumps of ore around the exterior of the pile, so as to form an outer wall of ore, whilst the smaller ore is placed along the sides of the draught-holes, with the larger pieces more distant from the heated currents passing through these passages. Such a heap, upwards of 100 ft. long, burns for one month, the combustion being maintained through the draught-holes formed throughout the whole mass of the pile; and the progress of the calcination checked by throwing smaller ore upon any parts indicating a too rapid rise in temperature.

In pyritous ores, the pyrites often occurs in laminæ, plates or nodules, arranged along the planes of stratification of the ore, and since the gases passing through the pile are largely of a reducing character, the sulphur is not completely oxidised. In order to facilitate the elimination of sulphur from such ores by the process of oxidation, it is important that the lumps or blocks of ore should be placed with their planes of stratification vertical, the surface of such piles being covered with small ore to condense and collect the sulphur.

Calcining or roasting in heaps involves a large consumption of fuel. In the South Wales and Staffordshire districts 2½ cwt.

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of coal (2 cwt. small and ½ cwt. large coal) are burnt per
ton of ore. It is difficult to regulate the temperature through-
out the pile, for whilst the ore in the interior is often clotted
or partially fused (especially with spathic carbonates or pyrit-
ous ores), the other portions may be insufficiently or incom-
pletely roasted. When much carbonaceous matters or pyrites
are present, their combustion locally intensifies the heat,
and so tends to clot the ore. Heap roasting is now almost
entirely abandoned in Britain.

Calcination between Walls.—Clay-ironstone is thus treated
in the Hartz, charcoal dust or breeze being the fuel. The walls
of the pile are from 6 ft. to 12 ft. high, and built round three
sides of a rectangular area, the floor sloping slightly towards
the front or open side. In the walls are two rows of draught
holes, each about 4 in. in diameter, the lower row being near
the ground level, and the second about 3 ft. higher up. These
draught-holes communicate with chimneys in the interior of
the pile built up of the larger pieces of ore, the chimneys
being connected with air-passages left in the base of the pile,
or formed by pieces of timber, and so the circulation of air
is effected. Less fuel is burnt, and the ore is more com-
pletely calcined.

Calcination in Kilns.—This process economises fuel and
labour, the temperature is under better control, calcination is
more uniform, and it is also continuous—as the calcined ore is
withdrawn from the bottom of the kiln, fresh raw ironstone
and fuel are added at the top.

In the Cleveland district, Gjers' kilns (Fig. 22) are gener-
ally used. They are circular in section, and are built of iron
plates lined with 14 in. of brickwork; they are about 33 ft.
high and 24 ft. in diameter at the widest part, having a capa-
city of about 8,000 cub. ft., holding, therefore, about 350 tons
of ore and fuel; but they are sometimes constructed of
larger size. A Gjers' kiln resembles a low blast furnace, with
a conical lower portion tapering towards the bottom; and
the whole is carried upon a cast-iron ring resting upon short
cast-iron columns, so as to leave a clear space of about 30 in.
between the bottom of the kiln and the ground. In the centre of
the kiln and resting upon the ground is fixed a cast-iron cone
with its apex upwards; this serves to direct outwards the
descending roasted ore, which is then raked outwards between

the columns carrying the kiln, whilst fresh ore and small coal are constantly added at the top to replace the ore withdrawn at the bottom. Around the body of the kiln, and near the bottom, are openings usually closed by doors; these admit air, and through them bars or other tools are passed to break up the clotted ore.

In Scotland the ore is calcined in vertical circular kilns not unlike small blast furnaces in appearance. The kilns
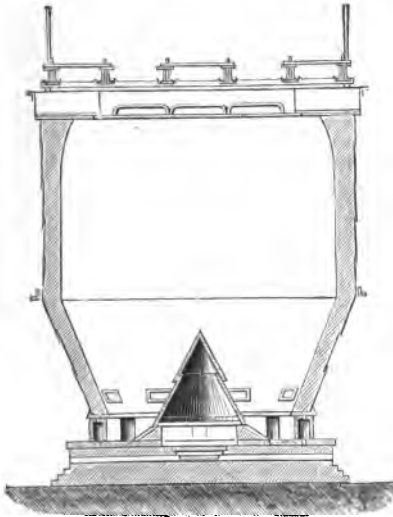
Fig. 22.—Gjers' Calcining Kiln, Vertical Section.
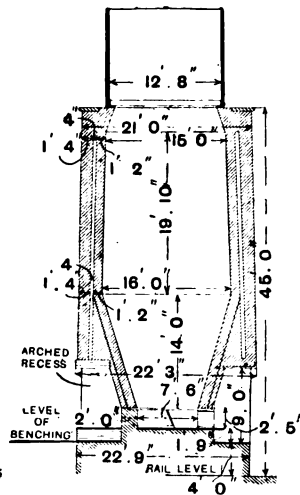
Fig. 23.—Scotch Calcining Kiln, Section.

are about 45 ft. high and 16 ft. in diameter, the charge is drawn through arches at opposite sides, it being thrown out-wards by iron plates forming a triangular prism across the bottom.

With a good kiln, calcining non-bituminous ores, the con-sumption of fuel will be about 0·7 to 0·9 cwt. per ton of ore.

Gas Kilns.—The Swedish kiln, heated by the waste gases of the blast furnace, is of circular section, slightly conical, and about 18 ft. high, with a mean diameter of 6 ft. It is formed of an external massive structure of brick or stone,

lined with firebrick and supported by bands of wrought-iron around its circumference. The gases from the throat of the blast-furnace are conveyed to a circular main at the base of the kiln, and thence introduced by sixteen equi-distant
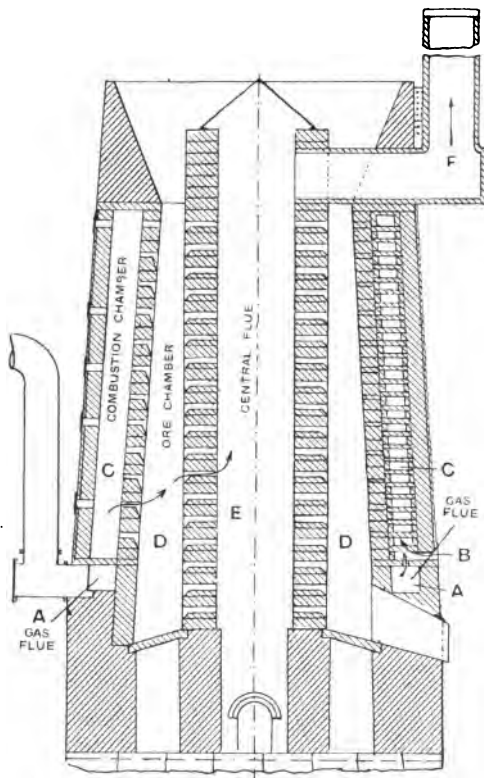
Fig. 24.—Davis-Colby Gas-fired Ore Roaster.

nozzles or jets ; the air necessary to combustion is admitted a little higher up through a series of apertures controlled by dampers, and still higher is another series of openings for the introduction of the bars required to break up the charge. Numerous other horizontal openings are left in the

brickwork, for the escape of moisture and other products of calcination ; at the base of the kiln are openings for the withdrawal of the charge. These kilns are capable of roasting about twenty-five tons of magnetite and schistose hæmatite in the twenty-four hours.

Where magnetic separation is to be used, it may be necessary to roast the ore in a reducing atmosphere, and for this purpose gas kilns are usually used, fired either by blast furnace or producer gas. Several forms of kiln have been devised, but the best known is the Davis-Colby, and is illustrated by Fig. 24. This consists of an annular calcining chamber D surrounded by a combustion chamber C, and surrounding a central flue E. The walls of the calcining chamber are perforated with a large number of openings. Gas and air are admitted to the chamber C, the proportions being regulated so as to give either an oxidising or reducing flame as may be required. The flame and products of combustion pass from the combustion chamber through the ore to the central flue, and thus to the chimney. The ore is supplied by hoppers at the top, and is drawn away through discharging doors at the bottom. The standard kiln is 45 ft. high and 24 ft. in diameter, and will calcine 300 tons of ore daily, with a consumption of 4 cwt. of coal for gas-production for each ton of ore calcined. Calcination is said to be very perfect, and the removal of sulphur to be complete.

Magnetic Concentration.—In various parts of the world magnetic ores occur which are contaminated by the admixture of pyrites, phosphate of iron, and other substances which reduce their value, and indeed often render them quite valueless for smelting purposes. These impurities are not magnetic, and in many cases can be separated by crushing the ore to a coarse powder and extracting the magnetic portion by means of magnets. This process is called magnetic concentration, and is now coming into use in Norway and other parts of the world. In order that magnetic concentration may be used, it is essential that the impurities to be removed be non-magnetic, and that they be present in such form that when the ore is crushed sufficiently finely the particles of magnetic and non-magnetic material will separate.

Many forms of magnetic separator have been designed, but it will be sufficient to describe one. Electro-magnets of

considerable power are almost always used, and the machine must be so arranged that the non-magnetic material does not remain entangled with the magnetic material. The power required will depend on the nature of the material to be separated—the greater its magnetic permeability, the less magnetic power will be required. Taking the magnetic permeability of pure iron as 100,000, that of magnetite is about 40,000, whilst red hæmatite is about 700, and limonite about 300. If the magnets be sufficiently powerful, hæmatite can be separated from a non-magnetic gangue, but its magnetic
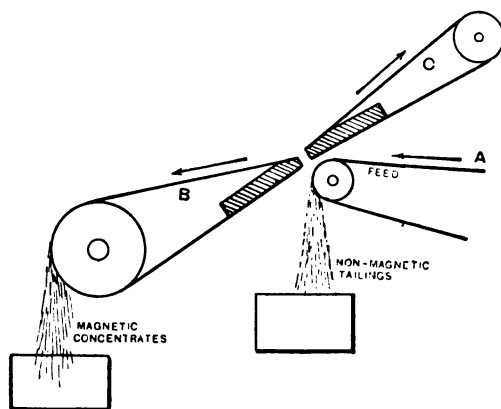
Fig. 25.—Wetherill Magnetic Concentrating Machine (Diagram).

permeability is so low that it is usually best to convert it into magnetic oxide. In the Wetherill machine, which may be taken as a type, the arrangement of which is shown diagrammatically in Fig. 25, two magnets, which may be either permanent magnets or electro-magnets, are used. These are bevelled at the edges, and the material to be treated is brought up on an endless belt which runs under one of the magnets. As the belt runs under or near the magnet the non-magnetic material falls off, whilst the magnetic material is attracted to another belt and carried to a separate receiver. The magnets may be vertical or inclined. In the form of machine shown in the sketch the ore is fed by the belt A, and the magnets are sufficiently powerful to draw the magnetic portions

over on to the belt B. The strength of current for the magnets and the speed must be determined for each ore. This machine has been used for the separation of franklenite and other slightly magnetic minerals, and by using a set of machines of varying strength, minerals of different degrees of magnetic permeability may be separated one from the other.

Most iron ores can be worked on machines of low power by first converting the iron into magnetic oxide either by heating or, better, by heating in a reducing atmosphere in a Davis-Colby or similar kiln, before crushing. Such ores as clayband and blackband ores cannot be successfully treated, as, however finely they may be powdered, they do not separate into the different constituents.

Magnetic concentration is at present chiefly used for treating poor and impure magnetites and hæmatites and such ores as franklinite.

Briquetting.—In order that magnetic concentration may be applied, the ore must be in a powder, and a powder is quite unsuitable for treatment in the blast furnace. It must, therefore, be made into blocks or briquettes which can be smelted. Large quantities of fine ore are now imported, and similar materials accumulate at many mines. These also are now frequently briquetted.

The ore for briquetting must be in the condition of a coarse powder. Magnetically separated ores are, of course, in that condition, whilst ores containing a large amount of smalls are screened to separate any pieces that are large enough for direct smelting, and the remainder is crushed to uniform size.

If the ore is at all argillaceous it will bind ; if not, some binding material is added — lime, some organic binding material such as pitch, or a small percentage of a good clay. The whole is thoroughly mixed in a mill or pan with sufficient water to make a stiff paste, and this is moulded into blocks, usually by hydraulic pressure. The blocks are dried, and then heated to redness or fired in a kiln. The briquettes may be of any convenient size, but are usually about 8 in. by 7 in. by 6 in., weighing about 35 lb. They must not be so large that they cannot be conveniently handled, and they must be strong enough to resist handling. It is quite obvious

that briquetting will add to the cost of the material, and the addition of binding material will reduce the percentage of iron. Purple ore—that is, burnt pyrites from which the copper has been extracted—is now largely made into briquettes for smelting, the alkaline salts present acting as a binding material.

The following analysis of Dunderland ore and of a briquette made from it may be of interest :—

	ORE.	BRIQUETTE.
Iron	49·350	68·550
Manganese oxide	1·116	—
Titanium oxide	·110	—
Alumina	·350	—
Lime	5·050	·450
Magnesia	·378	·144
Silica	16·300	2·300
Sulphur	·025	·030
Phosphoric Acid	·415	—
Phosphorus	—	·016
Carbonic Acid	5·700	—
Water	·450	—
Organic Matter	·200	1·900

In this case the binding material was organic matter.

CHAPTER VII.

CHANGES IN THE BLAST FURNACE.

The blast furnace in which the iron ore is reduced is a vertical stack of masonry cased with iron. The charge of solid material ore fuel and flux is introduced at the top and air is blown in at the bottom whilst the products of combustion escape at the top. The solid contents are melted and are tapped out through holes provided at the bottom of the furnace, and nothing can leave the furnace unless it be in the gaseous or liquid condition.

Chemical Changes.—Pig-iron is produced on a large scale from the ores which have been already described, and whatever may be the condition of the iron in the ore, it is always as oxide that it enters the furnace. The chemical reactions which occur in the smelting of iron are very simple, involving only the reduction of ferric oxide by carbon or carbonic oxide; but the product obtained by the reduction is a sponge of malleable-iron, enclosing the refractory gangue or earthy matters accompanying the ore, and this spongy iron is infusible. To produce pig-iron the reduced iron must be combined in the blast furnace with a proportion of carbon and silicon, whereby the metal becomes more fusible, and so separable by fusion from the gangue accompanying the ore. To prevent the loss of iron arising from the formation of rich ferrous silicates by unreduced oxide of iron combining with the silica present, a flux is added to the charge to combine with the siliceous matters of the ore, and thus prevents the formation of iron silicates (which are only reducible with difficulty), and leave the ferric oxide in a state to be readily reduced by the carbonic oxide in the furnace, or by the carbon of the fuel. Thus to extract the whole of the iron, a temperature above redness must be employed, and a flux must be added to form a fusible slag with the gangue of the ore.

The gangue accompanying iron-ores is usually either of a siliceous or of an argillaceous character, and is infusible

at the highest temperature of the blast furnace ; but by the addition of-lime to the charge comparatively fusible silicates of lime and alumina are produced. At the high temperature necessarily maintained in the blast furnace, the reduced iron combines with an amount of carbon derived from the incandescent fuel in the furnace, or from the finely-divided carbon with which the mass of ore in the furnace is impregnated, and pig-iron results.

When the blast-furnace is in regular work (" in blast "), it must be kept filled to the top or throat with the mixture of fuel, ore, and flux, fresh materials being added to the top as the charge sinks down. At the same time, the blast entering through the tuyeres near the bottom of the furnace is constantly and uninterruptedly supplied, except when tapping the furnace, or (sometimes) when opening the furnace top to introduce the charge. The blast should be delivered at sufficiently high pressure to pass freely through the whole charge, and for this a pressure of from 3 lb. to 12 lb. per sq. in. in furnaces employing coke as the fuel, or from 1½ lb. to 2 lb. per sq. in. in those consuming charcoal, is required according to the size of the furnace.

Reduction of Oxide.—The action of the blast furnace begins immediately the blast from the tuyeres meets the incandescent fuel (coke or charcoal). The oxygen of the blast is consumed within a small distance of the tuyeres, carbon - monoxide being produced and a large amount of heat evolved. The temperature is so high that no carbon-dioxide is produced, and if it were it would be at once decomposed. The gas which ascends the furnace consists, therefore, of a mixture of carbon monoxide and nitrogen from the air. As air contains 21 per cent. by volume of oxygen, and as carbon-monoxide occupies just twice the volume of the oxygen which it contains, the ascending gas will contain 79 parts of nitrogen to 42 parts of carbon-monoxide, or 65·3 per cent. nitrogen and 34·7 per cent. of carbon-monoxide, together with a small quantity of hydrogen from the decomposition of water in the blast. The carbon-monoxide is the principal and active reducing agent of the blast furnace, and it ascends along with the heated nitrogen introduced with the blast of air, together with smaller quantities of other gases, such as hydrogen, etc., it gradually

cools and imparts its heat to the descending charge. The ore is in a porous condition from its previous calcination, or from being heated in the upper portions of the furnace, and is thus in a state highly favourable to its permeation by the current of ascending reducing gases, and therefore to the reduction of the iron. The reduction of the iron is mainly effected by the carbon-monoxide, which is converted thereby into carbon-dioxide. Thus $Fe_2O_3 + 3CO = 3CO_2 + 2Fe$, whilst possibly a small proportion of the iron may also be reduced from the ferric oxide (Fe_2O_3) by the direct action of carbon, at the high temperature of the furnace. The nitrogen and other gases which do not act as reducing agents assist by their sensible heat to raise the temperature of the materials in the upper part of the furnace ; and hence the higher the furnace the more perfectly is the heat absorbed from the ascending gaseous current, with a corresponding decrease in the temperature of the gases escaping from the top of the furnace, although the escaping gases from both the high and the low furnaces may contain the same percentage of combustible gas, and yield as much heat upon their subsequent combustion.

As the reduction of the iron by carbon-monoxide begins at a temperature below that at which carbon-dioxide is decomposed by carbon, the carbon-dioxide formed escapes in the waste gas. The whole of the oxide of iron should be reduced by carbon-monoxide before the temperature is high enough for the carbon to decompose the carbon-dioxide ; that is, about a red heat. Any oxide of iron which is not so reduced will either be reduced by the solid carbon of the fuel or, if by carbon-monoxide, the carbon-dioxide formed will be decomposed, in either case causing a loss of carbon by oxidising it near the top of the furnace, where it is not required, instead of at the tuyeres. When all the iron is being reduced by carbon-monoxide, the ratio of carbon-dioxide to carbon-monoxide in the waste gas (by volume) will be about 1 : 2. As the gas contains a large percentage of carbon-monoxide it is always combustible.

The limestone added to a flux is decomposed at a red heat, and the carbon-dioxide evolved is decomposed by the hot carbon, and therefore leaves the furnace as carbon-monoxide and consumes a small quantity of carbon.

The reduction of the iron is probably not quite so simple,

but probably takes place in stages as the temperature rises, lower oxides being formed as intermediate products.

Carburisation of the Iron.—The iron thus reduced is accompanied in its descent towards the furnace hearth by the earthy matters of the ore, and lime from the limestone added as flux, and during the descent of the iron it is further carburised by contact with the heated carbon, or by the decomposition of carbonic oxide with separation of free carbon, thus $2CO = C + CO_2$, an action which takes place readily in high temperatures in presence of free iron. Then the fusible compound of iron with carbon and other impurities constituting pig-iron sinks down and collects in the hearth of the furnace, above which, in virtue of its lower specific gravity, floats the fusible slag, which is formed when the earthy constituents of the ore and the lime from the flux are heated to a high temperature, and which protects the metal in the hearth from the decarburising influence of the blast which enters above it.

Reduction of Other Constituents.—The whole of the phosphorus, whether derived from the ore, fuel, or fluxes, finds its way into the pig-iron produced in the blast furnace, so that the only way to obtain an iron free from phosphorus is to use phosphorus free materials. The reduction of the phosphorus is probably due to the presence of silica.

Manganese occurring in the iron-ores will be found partly in the resulting pig-iron and partly in the blast furnace slag, as a rule about one half going into the iron and the remainder into the slag.

The sulphur in the ore is largely expelled during calcination, but such as enters the blast furnace is found along with that in the fuel or fluxes, either in the resulting pig-iron or in the slags, according as the slag is calcareous or siliceous in character. When lime is in excess in the furnace, the sulphur tends to pass into the slag as calcium sulphide, especially if the temperature be high ; but if the temperature be low, iron sulphide is more stable and tends to pass into the iron. Hence, white iron, which is produced at a lower temperature than grey iron, is usually more sulphurous than grey iron, so that a high temperature with a liberal use of lime are the conditions favourable to the make of grey pig and the elimination of sulphur from the iron, whilst a proportionately larger

percentage of sulphur will occur in the slag than is found with the lower temperature accompanying the make of white iron. The larger proportion of the sulphur always goes into the slag, a comparatively small quantity going into the iron.

A comparatively high temperature is necessary to reduce silicon, and the higher the temperature of the furnace the richer in silicon is the resulting pig-iron likely to be ; thus the higher grades (*i.e.* lower numbers) of iron, which are always produced at higher temperatures, are more siliceous than the lower grades. Too high a temperature and not enough lime will sometimes produce a metal having a finely crystalline fracture and a bright lustre ; such pig is known as glazed or glazy pig, and it contains a high percentage of silica. Such pig is almost worthless either for foundry or forge use, and the remedy for a furnace producing such metal is either to lower the temperature of the blast, which is the most convenient method, or to attain the same end by increasing the burden of the furnace, and at the same time it increases the amount of lime in the charge. Such irons are made for special purposes, and are then known as silicon irons.

Manganese is always partially reduced, in general about one-half passing into the iron. The conditions which favour the reduction of manganese are a high temperature and a basic slag, since if the slag is siliceous it will tend to carry a large percentage of manganese.

Ferromanganese requires for its production a blast of the highest possible temperature that can be produced in fire-brick stoves, while the consumption of fuel is exceedingly high, amounting to about $3\frac{1}{2}$ tons of coke per ton of metal (80 per cent. manganese) ; a furnace that could yield from 50 to 60 tons of ordinary pig-iron per day yields only 12 to 20 tons of ferromanganese per day. Of the manganese present in the furnace charge, from 60 to 70 per cent. only is reduced and passes into the ferromanganese, while the remainder passes largely into the slag, but a portion also is most probably volatilised at the high temperature employed.

Chromium is very difficult to reduce, a very high temperature being required, so that each ton of ferro-chrome will require the consumption of three or four tons of coke. The whole of the chromium should be reduced or the slags will be thick and viscid. As this is not always possible, fluor spar or

other fluxes are added to increase the fluidity of the slags.

Cyanides.—The blast furnace when at work always contains cyanides. Some of the alkalies—soda and potash—probably present as carbonates, are always reduced. The alkali metal in contact with carbon and nitrogen of the air
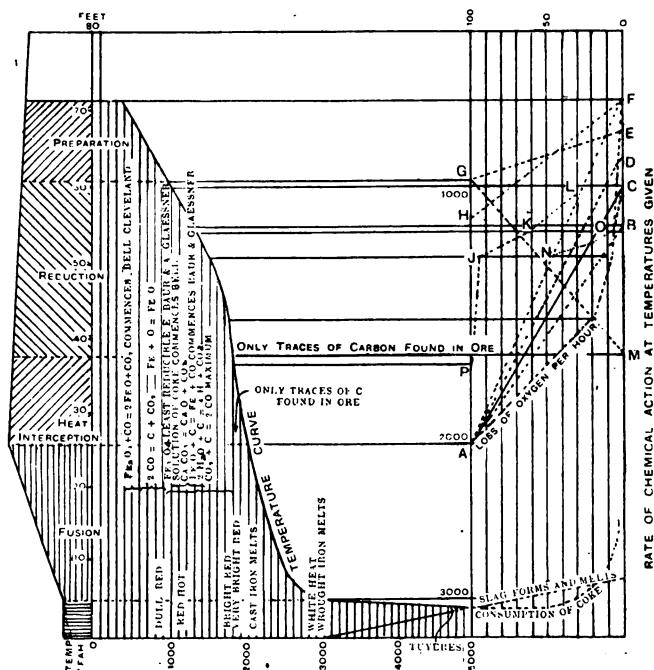
Fig. 26.—Temperature Reactions in Blast Furnace.

forms cyanide : $Na + C + N = NaCN$. This is volatilised, but is condensed before it reaches the top of the furnace, and is brought down again only to be re-volatilised. So the cyanides in the furnace tend to accumulate. When the tap-hole is opened, some is often blown out, and forms a white incrustation on the furnace-front. Some authorities think that these cyanides assist in the reduction of the iron.

Temperature and Zones of Blast Furnace.—The changes which take place in the blast furnace are, of course, largely determined by the temperature of the furnace. The temperature is highest at the zone of combustion just opposite the tuyeres, and the ascending gases are cooled by the descending charge, so that the temperature at the top of the furnace will not be visibly red, usually about 300° C. or thereabouts. The reduction of oxide of iron by carbon monoxide begins at about 300° C. and becomes much more rapid as the temperature rises, so that the conditions at the top of the furnace
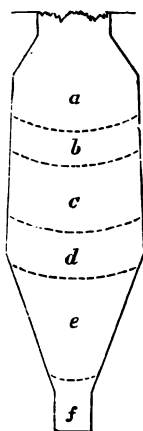
Fig. 27.—Zones of Action in the Blast Furnace Indicated by Diagram.

are very favourable for reduction, carbon monoxide being in large excess.

In the zone *a* (Fig. 27) at the top of the furnace the new charge is in course of being heated by the ascending gases, and within 20 ft. from the throat the charge has attained to a dull red heat, and the whole of its iron is reduced by carbonic oxide, with the production of a spongy metallic mass. This is the upper zone of reduction. Here also moisture will be expelled, and if coal is being used as fuel, gas and volatile matter will also be expelled. In the zone *b* the furnace is at a red heat, and the carbon-dioxide is being expelled

from the limestone, and coming in contact with the hot carbon will be reduced to carbon-monoxide; at *c* there is a full red heat, and the spongy metal begins to combine with carbon, either from that which has been deposited by decomposition of carbon-monoxide, or partly from the incandescent fuel, etc. This absorption of carbon continues through the next zone *d*, which is at a bright red heat, and where it is probable also that the reduction of sulphur, silicon, phos-phorus, etc., of the charge, and its combination with the iron, is effected; at *e*—the bosh of the furnace—the temperature has reached full whiteness, and is sufficient to effect the combination and fusion of the slag - producing materials; whilst in the lowest zone *f*, or hearth of the furnace, the slags are thoroughly fused, and separate accordingly from the pig-iron; the iron sinks, and collects as the lowest layer on the bottom of the furnace, where it is protected from the action of the blast by the layer of fluid slag above it.

The production from a given blast furnace is not perfectly under control, but generally white iron is produced when the furnace is worked at a low temperature, and with heavy burdens—that is, with a large proportion of ore to fuel, and a fusible slag, as under these conditions the quantity of silicon reduced is small, whilst a considerable amount of sulphur may pass into the iron. With an increased temperature and lighter burdens the pig-iron is usually grey and more siliceous. Hence, to obtain an increased make from the same materials whilst maintaining the quality of the pig-iron, the other conditions of ore and charging remaining the same, it is necessary to enlarge the furnace. If the make be increased by heavier burdening, other conditions remaining the same, the quality of the pig-iron is deteriorated, often turning the make into white iron, with the production at the same time of a scouring slag containing ferrous silicate. The nature and quality of the slag produced in the furnace varies with the quality of the metal produced.

Blast Furnace Slags.—The gangue or earthy matters of the ore, consisting chiefly of quartz (silica), clay (aluminous silicates), or of calcium carbonate, together with the earthy matters or ash of the fuel, are separately quite infusible or fusible only with difficulty; and therefore it is necessary to add some substance (flux) capable of combining with them

to produce readily fusible compounds or slags. As the gangue to be fluxed away is usually silica, or clay (a silicate of alumina), and by the addition of lime, fusible silicates of lime or lime and alumina can be produced, lime being added for convenience in the form of limestone, a carbonate. To reduce the amount of limestone needed different iron ores often are mixed together, the gangue of the one acting as a flux to the other. For instance, by the judicious mixing of siliceous and calcareous hæmatites, or by the addition of argillaceous ores to such a mixture, the necessary slag is produced, without the addition of a large amount of limestone. Some of the red hæmatites of Sweden, etc., contain sufficient calcareous matter to act as the flux ; they are accordingly very economical in fuel, and are known as " self-going " or " self-fluxing " ores.

The nature and quantity of the flux depends accordingly upon the character and composition of the gangue accompanying the ore ; for a gangue containing silica clay or similar material limestone is the flux always employed. Without a flux the silica alone is infusible, but would at the hottest zone of the furnace combine with ferrous oxide from the ore to produce a fusible ferrous silicate, the iron in which would escape reduction. When limestone is added, it becomes converted by the heat into caustic lime, and then combines with the silica and alumina of the ore, producing a fusible double silicate of lime and alumina, to the practical exclusion of iron from the slag. For ore having a quartzose or siliceous gangue, such as the hæmatite ores of Lancashire, Cumberland, etc., both lime and argillaceous matters are often added, the last mentioned often in the form of an iron-ore (such as Antrim) which contains alumina. Bauxite, a mineral containing about 57 per cent. of alumina and 25 per cent. of ferric oxide, is another flux sometimes used for siliceous ores. With the very high temperature now used in blast furnace working, the slags are essentially silicates of lime, the quantity of alumina being small except when clay ironstones or argillaceous ores are being smelted, and argillaceous fluxes are little used except in districts where small furnaces are in use.

Highly fossiliferous limestones contain much earthy phosphates and pyrites, and so are to be avoided as fluxes ; and dolomites (magnesian limestone) are also undesirable,

G

since magnesia decidedly diminishes the fusibility of blast furnace slags.

The use of caustic lime instead of raw limestone has been suggested, but it is rarely employed. The lime is considerably lighter than the limestone, but it is powdery and troublesome to handle. Probably it absorbs carbon dioxide at the top of the furnace, thus being converted into carbonate, which is decomposed again as the temperature rises. There is, therefore, no saving of heat. In rare cases the limestone is added to the kiln and calcined with the ore, but this does not seem to be any advantage.

ANALYSES OF BLAST FURNACE SLAGS.

	A	B	C	D	E	F	G	H
Silica . . .	38·48	43·07	39·52	36·50	31·46	29·00	27·68	42·96
Alumina .	15·13	14·85	15·11	22·59	8·50	19·00	22·28	20·20
Lime . . .	32·82	28·92	32·52	32·68	52·00	40·00	40·12	10·19
Ferrous oxide	0·76	2·53	2·02	0·06	0·79	—	0·80	19·80
Manganous oxide . .	1·62	1·37	2·89	0·32	2·38	—	0·20	1·53
Magnesia . .	7·44	5·87	3·49	5·83	1·38	8·5	7·27	2·90
Calcic slphd.	2·22	1·90	2·15	—	2·96	5·5	2·00	1·32
Sulphur . .	—	—	—	1·74	—	—	—	—
Alkalies . .	1·92	1·84	1·06	0·96	—	—	—	1·10
Phosphoric anhydride	0·15	—	—	—	—	—	—	—
	100·54	100·35	98·76	100·68	99·4	100·00	100·35	100·00

A.—From Dowlais making grey iron (Riley). B.—From Dowlais making white iron (Riley). C.—Cold blast furnace working with coke (Percy). D.—Cleveland slag. E.—Producing grey Bessemer iron slag, disintegrates in air. F.—Scotch slag. G.—From Cleveland ores (Bell). H.—Scouring cinder, South Wales pig (Nord).

Slags from the blast furnace differ in physical character according to the nature of the ore and the fuel; to the quality of the pig-iron being produced; and also as the burden of the furnace varies from light to heavy. Blast furnace slags are usually double silicates of lime and alumina, of the composition represented by the formula $2RO, SiO_2$ where R is usually partly lime and partly alumina, the lime almost always being in large excess. A typical formula $3(2CaO,SiO_2) + 2Al_2O_3 3SiO_2$, in which the two bases are in equivalent

proportions, is often given, but is rarely met with in practice.
More siliceous slag is often produced by charcoal furnaces;
is always more or less replaced by magnesia (MgO),
oxide (MnO), and in the case of "scouring
ferrous oxide, whilst the silica also sometimes
ced to a small extent by alumina; the slags
a small quantity of potash and soda. Slags
larger proportion of manganous oxide, or of
quently contain also a larger proportion of sulphur.

The colour of blast furnace slags varies from white or
grey, through varying shades of brown, yellow, green, and
blue, to black. Generally a white or grey slag is indicative
of a furnace producing grey iron, and working upon a light
burden; whilst dark-coloured or black slags result when
the furnace is making white iron and working upon a heavy
burden or a highly siliceous iron with a very siliceous slag;
but the colours of the slags are also influenced by the bases
present. Metallic oxides give the slags their distinctive
tints; for instance, the presence of small proportions
of manganous oxide in the slag produced during the
smelting of manganiferous hæmatites gives an amethyst
tint, which, however, is not apparent when the slag is vesicular
or pumice-like in structure. Manganous sulphide also imparts
a yellow or brownish-green colour to the slag, and the pres-
ence of excessive proportions of alumina manifests itself in
the production of an opalescent slag, such as is frequently
observed in Staffordshire from furnaces smelting clay iron-
stone. Lime, when in considerable proportions, is indicated
by a dull, stony fracture of the slag, and if it becomes excessive,
—*i.e.* more than that required for the formula $2CaO,SiO_2$;
free lime separates as the slag solidifies, and therefore on
exposure to a damp atmosphere it disintegrates and falls
to powder; such slags, when ground and mixed with about
one-fourth of their weight of caustic lime, yield a good
cement or mortar for building purposes. Slags containing
a large proportion of lime also take up a considerable quantity
of the sulphur present in the fuel and in the ore, with
the production of calcium sulphide, the presence of which
is evidenced by the evolution when the slag is quenched
with water of the characteristic odour of sulphuretted hydro-
gen (H_2S), or of sulphurous anhydride (SO_2) if the slag be

not so far cooled as to prevent the escaping gas (H_2S) from taking fire on coming into contact with the atmosphere. A similar liberation of sulphuretted hydrogen occurs when barium or manganous sulphide is present in the slag which is treated with water.

The appearance of the slag depends largely on the molecular condition induced by the varying rapidity or method of its cooling. Thus a slag which has been cooled quickly will be vitreous and have conchoidal fracture, and be more or less translucent on the thinner sections, whilst if a similar slag be cooled more slowly it will show on fracture dull, stony, and opaque, and the same slag if allowed to flow over damp sand or through water will become changed to a vesicular, brittle, friable, and pumice-like mass, from the action of the steam passing through it.

The fusibility and fluidity of the slag also to some extent indicate the working of a furnace ; under the same general conditions a refractory slag means grey iron, and a very fusible slag white iron. Slags which flow in continuous, steady, but more or less viscous streams, passing slowly from the liquid to the solid state, are often produced when a furnace is working upon light burdens, and have generally a grey or whitish colour ; whilst heavy burdens and a reduced temperature of the furnace are accompanied by a scouring slag or cinder, flowing as freely as water, and readily solidifying without passing through the viscous condition. These scouring slags are often also of a dark-green or greenish-black colour from the presence of ferrous oxide.

Thermal Phenomena of the Blast Furnace.—The heat which is supplied to the blast furnace is used in various ways, and it is of great importance to know what becomes of the heat so as to be able to judge the economy with which the furnace works.

Heat is supplied by the combustion of the fuel, and by the heat carried in by the blast, which is now always used hot, and the heat is either utilised in producing chemical changes within the furnace, carried off with the products from the furnace, or lost by oxidation or otherwise.

Sir Lowthian Bell, from a series of experiments, made out an estimate of the amount of heat required to work a blast furnace under the ordinary Middlesbrough conditions, and

this estimate will give a very good idea of the way in which the heat is utilised. It is calculated for 20 parts (lb. or otherwise) of iron obtained, the heat units used being the 1 lb. Centigrade units—that is, the amount of heat required to raise 1 lb. of water 1° C. Notes are attached explaining the meaning of each item.

		LB.		HEAT UNITS.
(1) Evaporation of water in coke . . .		·58 ×	540 =	313
(2) Reduction of 18·6 lb. of iron from Fe_2O_3 .		18·6 ×	1,780 =	33,108
(3) Carbon impregnation		·6 ×	2,240 =	1,440
(4) Expulsion of CO_2 from limestone . .		11 ×	370 =	4,070
(5) Decomposition of CO_2 from limestone .		1·32 ×	3,200 =	4,224
(6) Decomposition of water in blast . .		·05 ×	34,000 =	1,700
(7) Reduction of phosphoric acid, silica, etc.				3,500
(8) Fusion of Pig		20 ×	330 =	6,600
(9) Fusion of Slag				15,356
				———
Heat usefully used . . .				70,311
(10) Transmission through walls of furnace .	.	. 3,600		
(11) Carried off in tuyere water . . .	.	. 1,800		
(12) Expansion of blast and escape into foundations		. 3,389		
		——		8,789
(13) Carried off in gas	.	.		7,900
				———
				87,000

The heat is obtained mainly by the combustion of the coke. If carbon be burned to carbon dioxide, it will evolve 8,000 units of heat, but if it be burned to carbon monoxide it will evolve only 2,400 units of heat. At the tuyeres it is burnt to carbon monoxide only, but other oxidations—mainly reduction of the oxide of iron—go on higher up the furnace, so that the gas which leaves the furnace contains about one-third of its carbon in the form of carbon dioxide and two-thirds as carbon monoxide. The average heating value of a pound of carbon so burnt will obviously be :—

$$\frac{(1 \times 8,000) + (2 \times 2,400)}{3} = 4,266$$

The coke which is consumed may be taken as containing 90 per cent. of carbon, so that the average heating value of 1 lb. of coke will be 4,266 × ·9 = 3,840 units. The heat carried in by the blast at 540° C. may be taken as being 12,000 units

for each 20 lb. of iron, so that $87,000 - 12,000 = 75,000$ will be the amount of heat to be supplied by the fuel, and to supply

this $\dfrac{75,000}{3,840} = 19\cdot53$ lb. of coke will be required.

The figures will, of course, vary with the conditions of working, but those given above apply to the special case.

Notes on Items of Heat Absorption.

(1) Roughly speaking, 20 lb. of coke will be required for 20 lb. of iron produced, so that $\cdot58$ lb. of water would be $2\cdot9$ per cent.—a very low estimate; 540 is the latent heat of steam.

(2) Pig iron is not pure. Here it is assumed to contain 93 per cent. of iron, so that the 20 lb. of pig iron would only contain $18\cdot6$ lb. of pure iron. The reaction, $Fe_2O_3 + 3CO = 2Fe + 3CO_2$, is obviously made up of two portions: the decomposition of Fe_2O_3, which absorbs heat, and the oxidation of CO to CO_2, which evolves heat. Account is taken of the latter in the heat evolved by the combustion of the fuel, so that it is only the heat absorbed that is taken into account here.

(3) It is assumed that the carbon is obtained by the decomposition of carbon-monoxide : $2CO = C + CO_2$. The formation of carbon-dioxide, of course, evolves heat, but this is taken into account as before with the fuel.

(4) The limestone is split up into CaO and CO_2. It is assumed that 55 lb. of limestone is added for each 100 lb. of iron obtained.

(5) The 11 lb. of limestone added for each 20 lb. of iron will contain $1\cdot32$ lb. of carbon as carbon-dioxide, the reduction of this to carbon-monoxide, $CO_2 + C = 2CO$, will absorb 3,200 units of heat for each pound of carbon. The formation of the carbon-monoxide will, of course, evolve some heat ; but this is accounted for by the combustion of the fuel.

(6) The air is never free from moisture. Assuming it to contain $\cdot05$ lb. of hydrogen for each 20 lb. of iron, the heat absorbed by the decomposition of the water, $H_2O + C = 2H + CO$, will be that given in the table. Here, again, the formation of carbon-monoxide will evolve some heat, but as

the carbon comes from the fuel this will be accounted for in the heat of combustion of the fuel.

(7) Reduction of minor constituents will absorb heat. The actual amount could be calculated if the amount of each constituent was given.

(8) Fusion of pig iron.—The latent heat of fusion of pig-iron, together with the heat required to raise it to the melting point, is taken as 330.

(9) The latent heat of slag used is not given.

(10) Can only be roughly estimated.

(11) The water used to cool the tuyeres becomes warmed and carries away heat.

(12) Can only be roughly estimated.

(13) The gas consists of carbon monoxide and hydrogen from the fuel, carbon monoxide from the carbon dioxide of the limestone, carbon dioxide from the reduction of the oxide of iron, and water vapour from moisture in the charge. The amounts of these could be calculated if data were given.

Efficiency of the Blast Furnace.—The blast furnace is a very efficient machine. Of the heat carried into the furnace —say, 87,000 units—no less than 70,311, or about 81 per cent., is usefully used ; that is, used in producing reactions that are necessary to the working of the furnace ; and the remainder is carried away in such ways as cannot be considerably reduced.

If the 19·53 lb. of fuel were completely burnt to carbon dioxide it would evolve 156,000 units of heat instead of 75,000, so that the difference (81,000 units) can be obtained by the combustion of the gas evolved from the blast furnace.

CHAPTER VIII.

The Modern Blast Furnace.—The modern blast furnace used for smelting iron ore, as seen from outside, is a cylindrical or slightly conical structure of iron, carried on iron columns provided at the top, with an overhanging gallery, and the lower portion with pipes supplying air and water (see Fig. 28). Fig. 29 is a section showing the furnace when empty. It consists of a casing of iron or steel plate, lined inside with bricks to a thickness of about 3 ft.

The furnace has its greatest diameter at about one-third its height, and narrows both upwards and downwards. The opening at the top or throat is about two-thirds the greatest diameter, and the furnace may either narrow uniformly to that; the upper portion being the frustum of a cone, or it may slope much less, and be quickly contracted near the top. This upper portion of the furnace is called the shaft. From its widest part, the furnace narrows more rapidly downwards to about half the greatest diameter, and this portion, which is in the form of an inverted cone, is called the bosh, which name is also given to the greatest diameter. Below the bosh there is a cylindrical portion or hearth, in which the molten material accumulates. The furnace is thus divided into three portions, which correspond roughly to the changes which take place. In the upper portion the charge is heating up and the various reactions are taking place, in the middle portion the charge is melting and therefore diminishing in volume, and in the lowest portion the melted material accumulates. The contour of the furnace may vary very much. There may be sharp lines of demarcation between the separate parts, or they may be curved gradually one into the other. Half a dozen typical shapes are shown by Figs. 30 to 35.
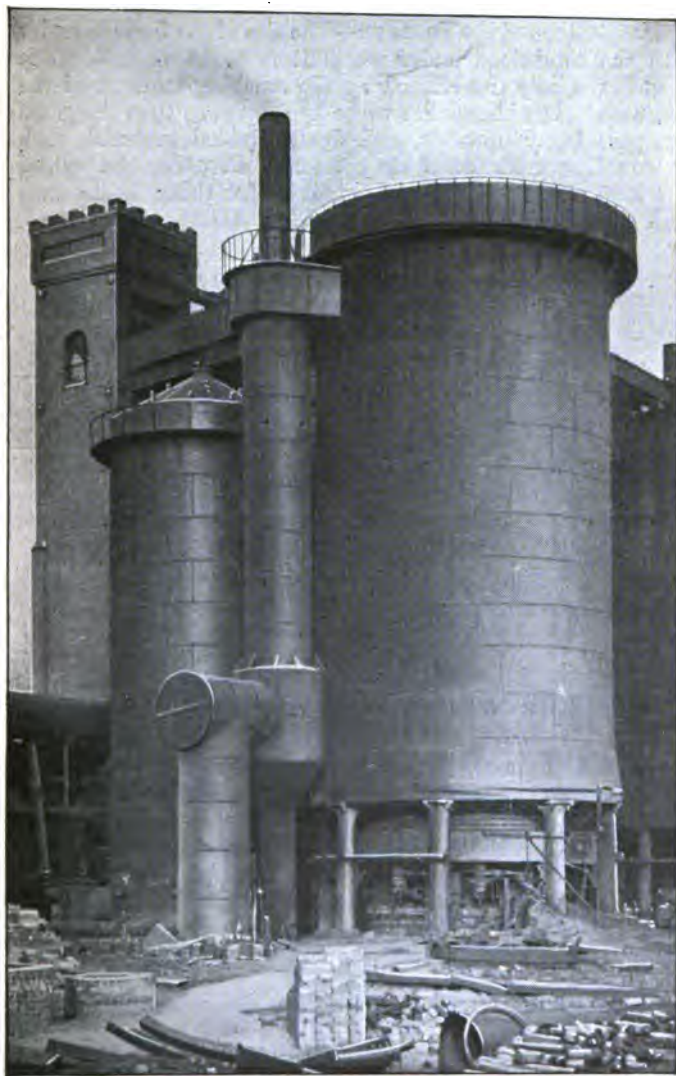
Fig. 28.—Modern Blast Furnace.

Proportions of the Furnace.—The size of the furnace varies with the conditions under which it is to be worked. The height is mainly determined by the crushing strength of the fuel used. The charge has to be kept open so that the gases can pass freely upwards, and finely divided material, such as would be produced if the coke crushed under the weight of a high column of material would hinder this. In districts such as Middlesbrough or the West Coast, where hard,
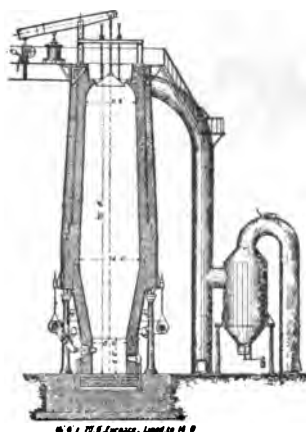

Fig. 29.—Modern Blast Furnace, in Section, with Dust Catcher.

strong coke is used, the furnaces may be 80 ft., 90 ft., or 100 ft. high, but in Scotland where the fuel used is splint coal, the coke from which crushes very easily, the furnaces are rarely more than 60 ft. high. Charcoal furnaces are for the same reason always small.

The diameter of the furnace at its widest part is usually from one-third to one-fourth of the height, two-sevenths being a very usual proportion. In some modern furnaces the proportion is about $\frac{1}{4 \cdot 5}$, and in some very old furnaces it is as low as $\frac{1}{2 \cdot 5}$.

The diameter of the hearth is mainly determined by the

Fig. 30.   Fig. 31.   Fig. 32.
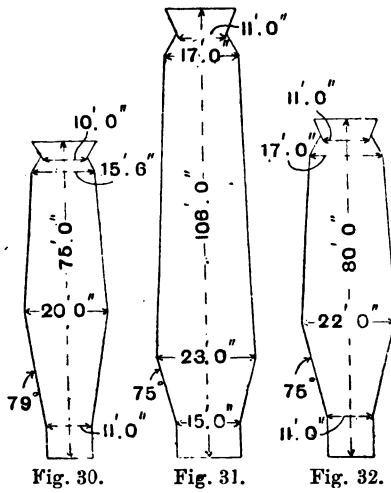
Figs. 30 to 32.—Blast Furnaces.

Fig. 33.   Fig. 34.   Fig. 35.
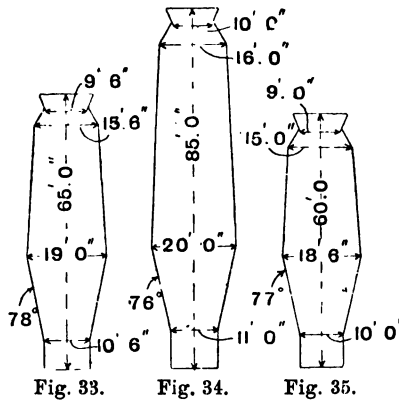
Figs. 33 to 35.—Blast Furnaces.

pressure of the blast being used, with a maximum of about half the diameter of the bosh. The air must penetrate to the centre of the charge; therefore, when the blast pressure used is low, small hearths must be used. In this country 8 ft. or 9 ft. is the usual hearth diameter, or a little more if the tuyeres are overhung; whilst in America, for a heavy blast pressure, 11 ft. is common. The angle of the bosh, that is the angle made with the horizontal by a line joining the top of the hearth with the bosh, is usually about 75°. The depth of the hearth varies with the amount of metal which it is to hold, but is usually about 6 ft.

Building the Furnace.—In building the furnace, the iron columns are erected, and on these are put lintel plates to carry the superstructure. The iron plates are then put on, and are lined as they are carried up. Sometimes a double layer of brickwork is used, an outer layer of ordinary brick and an inner layer of firebrick, the two being separated by a layer of ashes about 2 inches thick to allow for expansion. In many modern furnaces, however, the whole lining is of firebrick. The bricks should be refractory and not too siliceous. They are always specially made to suit the curvature of the furnace, and are set in fireclay. Holes are left in the casing so as to allow of the escape of steam as the brickwork dries. Sometimes, in place of the iron casing the furnace is banded or crinolined with iron hoops. In this case the masonry is the essential part of the structure, and must be made stronger, but the tendency in modern furnaces is to rely on the shell for strength, using the bricks merely as a lining.

As soon as the columns are up the bottom of the hearth can be put in. This is about 4 ft. to 6 ft. thick, made either of very refractory stone, firebrick, or concrete. It is extended to the outer diameter of the walls of the hearth, so that the weight of the masonry above prevents it being lifted bodily should molten iron find its way underneath, and the separate stones or bricks are so shaped and fitted that no portion can be lifted. On this the circular wall of the hearth is built. It is about 3 ft. thick, and in modern furnaces it is strongly cased in cast-iron plates bolted together.

From the top of the hearth, the walls of the bosh are built up till they join the walls of the shaft above. As the

inverted cone would not be a stable structure, it is strengthened by bands of iron round every second layer of bricks, or is often completely cased in iron. In order to save the brick-work of the bosh it must be kept as cool as possible. The columns are therefore made as high as possible to allow free access of air. The bosh walls are made about 1 ft. 6 in. to 2 ft. thick, and when the furnace is to be driven hard, the bosh is cooled with water. This can be done by building into the masonry a series of blocks, either of iron or bronze, through which water can be made to circulate ; or water may be circulated round the casing of the bosh. If a furnace is to stand well, the bosh must be kept cool.

The Bell and Cone.—The older furnaces were worked with an open top, the throat was surrounded with a sort of chimney, " the tunnel head," with openings for charging, and the gas was allowed to burn at the top of the furnace. Attempts were made to utilise the gas as far back as 1836. The invention of the bell-and-cone charging apparatus by Parry in 1850 solved the difficulty of drawing off the gas, with-out interfering with the charging, and from that time the utilisation of the gas became general. The gas, as already mentioned, is combustible and therefore is of great value as fuel. The bell-and-cone charging apparatus is now almost invariably used. The top of the furnace and the charging gallery is covered with iron plates up to the edge of the throat. An iron inverted cone about 6 ft. deep is fixed in the throat of the furnace, the slope being more or less steep according to the diameter of the throat of the furnace and the diameter required for the bell. It is now common to narrow the throat of the furnace considerably and use a very steep cone. The cone is of cast-iron, cast in four or more pieces with projecting flanges by which the parts are bolted together. Usually there is a separate bottom ring bolted on, which can be removed if necessary, so as to allow the bell to be lifted out. Inside the cone is hung a conical bell of such size that it will not draw through the bottom opening of the cone, so that when the bell is up, it presses all round against the cone, and when it is down, it leaves an annular opening all round. The bell may be of cast iron, but is usually composite, that is it consists of a cast-iron cap and a cast-iron bottom ring, cast in sections, the two being united by sheet-iron or steel stiffened,

if necessary, with steel rods. Such a bell is both lighter and stronger than one of cast-iron. The bell (Fig. 36) is suspended at the end of a beam by iron links or chains, additional safety chains being usually attached so that, in case the supporting link should give way, the bell would not be lost. At the other end of the beam is a balance weight heavy enough to keep up the bell, and an arrangement by which the bell can be fixed firmly in position. At the end of the bell over the cone is hung an iron basket in which a fire is kept burning, so that when the bell falls, the gas which escapes may ignite. The charge of ore fuel and flux is brought up in barrows and emptied on to the space between the bell and cone, care being taken to put the materials so that the charge in the furnace shall be as well mixed as possible. About
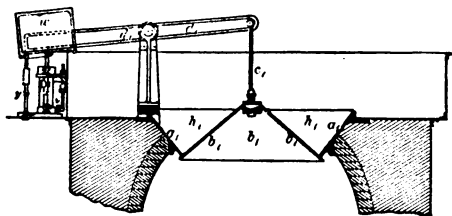

Fig. 36.—Bell and Cone Charging Apparatus : b, bell ; h, cone ; d, bell lever ; w, balance weight ; y, catch of fastening lever ; x, cataract.

four or five tons of material is put on before the bell is lowered, and that is sufficient to overweigh the balance weight, so that as soon as the fixing catch or screw is released, the bell drops, the charge slips into the furnace, a rush of gas escapes from the top, which at once ignites, and the balance weight brings the bell back into position, where it is at once fixed. A little powdered material, such as purple ore or coke, is thrown round the bell to make the joint tight, and it is ready for the next charge. A bell working as described would be brought to rest too suddenly and would jar. To avoid this a cataract is often employed. This consists of a cylinder of water in which is a piston attached to the balance weight end of the bell beam, the upper and lower portions of this cylinder being connected by a small pipe in which is a stopcock. It is obvious that if the stopcock is closed, no

water can flow, and the piston and the bell cannot move. If the stopcock is opened, water can flow from one end to the other, and the bell can ascend or descend. The inertia of the water retards the motion, and thus diminishes the shock. The lowering and raising of the bell takes about 15 seconds.

Many other methods of operating the bell are in use. The bell can be made slightly heavier than the balance weight, and it can be brought up by a hand wheel working in a rack on the end of the beam, or by a screw or any other device. At one time the blast was put off when the bell was lowered, but this is now rarely done.

The bell needs some space so that it can be lowered, and this, with the depth of the bell itself, prevents the furnace being filled to the top. The space usually allowed is from 8 ft. to 10 ft.

Charging the Furnace.—The material for charging the furnace is put into barrows, each holding about 1 ton, either from ore bins or direct from the railway trucks. These are hoisted to the top of the furnace, wheeled by the charger to the cone, and emptied on to the bell. This method answers quite well for moderate outputs, but where a large output is required mechanical charging must be used. The material is carried up an inclined plane in a skip or bucket which is automatically emptied on to the bell (see Fig. 37). To prevent the charge always falling on the same part of the bell, which would lead to irregular working, a hopper into which the material is shot is fixed above the bell. This is arranged so that for each ascent of a skip it is rotated one-eighth or one-fourth of a revolution, and thus the charge is evenly distributed round the bell.

The Gas Mains.—Just below the charging platform, and opening into the space beneath the cone, is the gas main, which is an iron pipe 5 ft. or 6 ft. in diameter. This is connected with a valve box, from which descends the gas downcomer pipe, and to the top of which is attached a vertical standpipe opening into the air. By means of valves, the gas can be directed either upwards or downwards. Ordinarily, it is sent direct into the downcomer main, but when necessary it can be turned into the standpipe, at the top of which it burns. At one time the gas was always turned into the standpipe when the bell was lowered. This is now rarely done, as there

is always a pressure of gas in the furnace, and the gas escapes
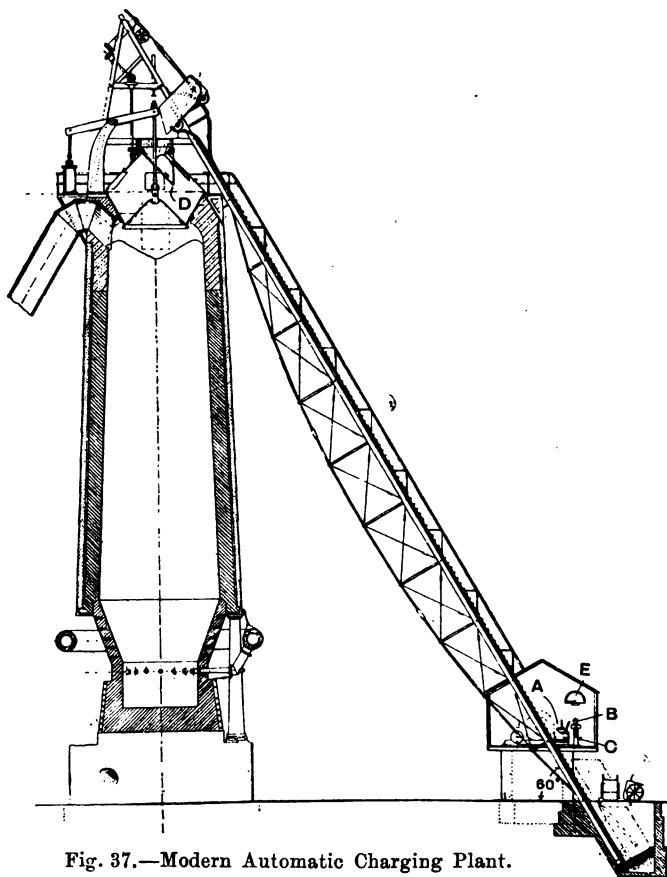rather than air being drawn in. The gas carries over with it

Fig. 37.—Modern Automatic Charging Plant.

dust from the charge, and to remove this it is passed through
a dust catcher (see Fig. 29). This is simply a large chamber,
much larger than the gas main, so that the velocity of the gas
is checked, and usually its direction is altered so that the

dust tends to fall out, and can be removed through the cleaning doors provided for that purpose.

Tuyere Openings.—Above the top of the hearth, a series of openings about 2 ft. wide and 1 ft. 6 in. high are left in the masonry (see Fig. 38). These are the tuyere arches or openings, and are to receive the pipes through which the air is sent into the furnace. The number varies ; in modern furnaces it is eight, ten, or twelve, but in the old furnaces it was three or six. In modern furnaces the tuyere arches are evenly spaced round the hearth. In

Fig. 38.—Front of Furnace, showing Tuyere Arches and Openings for Slag and Metal Tap Holes.

the older furnaces, in which the hearth could usually only be approached by four arches through the heavy masonry base of the furnace, tuyere arches were provided in three of these, the fourth or front of the furnace, where the tap hole is, not having a tuyere, or at least only a small one, called a " monkey."

The air from the blowing engines and hot-blast stoves is brought up to a main which almost encircles the furnace, and is called the " horseshoe " main. It is of iron, and is lined with firebrick, and sometimes is also covered with a

H

non-conducting coating. The horseshoe is almost always carried on iron brackets bolted to the furnace columns, or in some modern furnaces it is suspended by iron links from the top girders. Opposite each tuyere arch, a vertical pipe descends to the tuyere level, and is provided with a sliding valve by which the air can be cut off from the tuyere when necessary.

The Tuyeres.—The tuyere is an iron or bronze pipe about 3 ft. long, and having a diameter at the small end of from 3 in. to 8 in., according to the amount of air to be sent into the furnace. A very common size is 4 in. This is connected with the downcomer by means of an iron tube. In the days of the cold blast a leather pipe was used, which was called a "goose-neck," and the name is sometimes used for the connection.
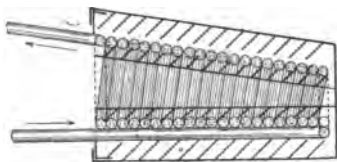

Fig. 39.—Scotch Tuyere.

The horizontal pipe must be fitted to the vertical down-comer pipe in such a way that it is air-tight, and at the same time can be quickly and easily removed. The end of the down-comer pipe is usually made conical, and is machined smooth, a hole to receive it being made in the upper side of the tuyere pipe (see Fig. 39). An iron link hung on studs from the downcomer is passed under the horizontal pipe and is screwed or wedged into position, so that it is firmly held. At the end of the horizontal pipe is an opening closed by a slide, which can be opened to allow the workman to clear the tuyere with an iron rod, should it become stopped. In the centre of this is a hole closed by mica or blue glass, through which can be seen a bright spot (the eye of the furnace), from which the workman can judge if the tuyere is properly open.

Water-cooled Tuyeres.—When the cold blast was used, the tuyere was laid in the tuyere arch and luted in with clay; but with the hot blast as now used, combined with

the heat of the furnace, the iron pipe would be rapidly destroyed. To prevent this, it is surrounded by a water jacket, which keeps the blast pipe enveloped in flowing cold water. The Scotch tuyere (Fig. 39), which is now generally used, was invented by Condie in 1829. It consists of a coil of wrought-iron pipe embedded in a mass of cast iron, with a hole in the centre in which the tuyere nozzle rests. The Staffordshire or box tuyere (Fig. 40) consists of a conical iron box with a hole through centre for the tuyere nozzle, a constant stream of water being kept running through. In a modern form, instead of keeping the box filled with water, a fine spray is delivered which keeps the whole cool. This spray tuyere has the advantage that there is no large mass of water to flow into the

Fig. 40.—Staffordshire Tuyere.

furnace should the tuyere break. Box tuyeres, whether water or spray, are best made of bronze, as being much less likely to crack than cast iron. In the forms of tuyere described, the water is delivered under pressure, and in case of fracture the water will flow into the furnace and may cause an explosion; to avoid this, a vacuum tuyere has recently been introduced. The water is drawn through by suction by means of a pump, so that should the tuyere fracture, water does not flow out, but gases are drawn in and can be at once detected.

With the hot blast now often used, the single water tuyere is not sufficient, and it is surrounded by a second water tuyere or cooler, commonly called a "jumbo."

The water from the tuyeres always flows out into an open channel, so that the workman can judge if it is flowing correctly and is about the right temperature.

Slag Tap.—At the top of the hearth, a few inches below the bottom of the tuyere arches, another opening is left in the masonry for the slag tap. This is built up with brickwork,

a hole being left for tapping out the slag.   Frequently a
water tuyere is fitted into this hole.   As the furnace works,
the metal sinks into the hearth with the slag above it.   As the
slag and metal accumulate they rise, and if not removed the
slag would soon reach the level of the tuyeres.   To avoid this
the slag hole, which has been stopped with clay, is opened
and the slag is run out.   The hole is then closed, and the

Fig. 41.—Slag Runners with Circular Slag Bogies.

tapping is repeated every hour or so from the time the slag
reaches the necessary level until the metal is tapped.

In front of the slag hole a sloping channel (Fig. 41) (the
cinder or slag fall), is made by which the slag is carried away.
The slag is often formed into large blocks by running it into
a slag-tub or bogie (an iron truck with movable sides), so
that, when the tub is filled and the slag has solidified, the sides
of the cinder-tub are lifted away by means of a crane, or if
hinged are turned downwards.   The mass of slag is then lifted
from the bottom of the slag-tub or bogie on which it stands,
and conveyed to the cinder-heap ; or the bogie itself is drawn
to the cinder-heap, and the block there thrown or tipped off

on to the heap. As the slag-bogie is filled, it is replaced by an empty one, or the channel is diverted so as to run the slag into another standing alongside the one just filled.

In Staffordshire, the slags collect in a cavity or basin in the ground or floor of the casting-bed, and known as the roughing-hole, from whence, after solidification, the slag is lifted into waggons and taken to the cinder-tip. To facilitate the removal of the slag, a conveyer is now frequently used. This consists of a series of shallow iron moulds carried on an endless belt, passing under the end of the slag shoot.
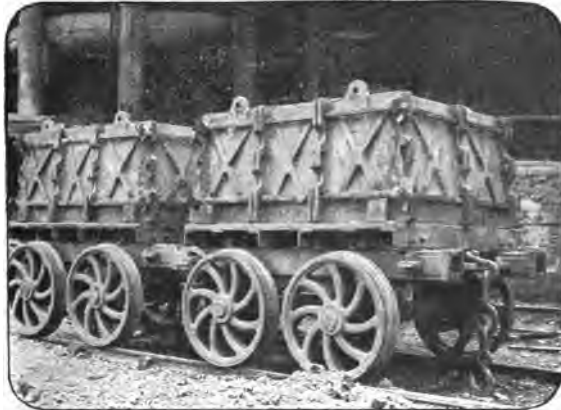

Fig. 42.—Square Slag Bogies.

The slag is allowed to flow continuously, and the moulds move at such a rate that each is filled as it passes under the shoot. The slag is solidified by a spray of water, and is automatically delivered from the conveyer to a truck in which it can be carried away to the slag tip.

Metal Tap.—At the bottom of the hearth, usually near the slag hole but not vertically under it, another opening is left in the masonry ; this is also closed up with brick-work, a hole about 6 in. in diameter being left, which is stopped with clay. When the metal rises nearly to the level of the slag hole, the furnace must ·be tapped. The workman places the end of a crowbar, resting on an iron

rod, against the clay of the tap hole, and by means of a sledge drives it in. As soon as an opening is made, the iron begins to flow. When the iron is all out it is followed by the residual slag, and as the liquid falls below the hole,
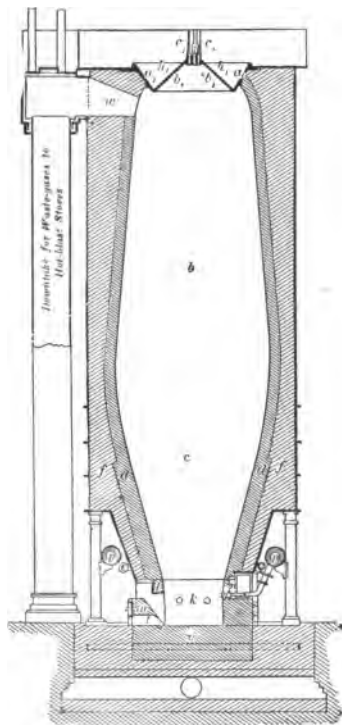

Fig. 43.—Blast Furnace with open Front, Vertical Section.

air escapes and sparks are ejected. The hole is now closed. The workman takes a lump of clay which has been mixed with water so as to be plastic, and throws it against the opening, pressing it with a rod so as to make it solid. A second lump is added and pressed in so as to make the tap hole quite secure. In America the clay is forced into position by means of a pneumatic " mudgun."

The furnace can be tapped every six, eight, or twelve hours according to the capacity of the hearth and rate of reduction. In Scotland the furnaces are tapped every twelve hours, and each tap yields about 25 tons of iron.

Older Open Front Furnaces.—In the older furnaces the arrangement was a little different. The hearth was not completely enclosed, but the front was extended a little beyond the furnace, the weight above being carried by an arch thrown across the space and called the "tymp" arch. This arch was often replaced by an iron girder kept cool by the circulation of water through it. The front of the hearth was closed by a vertical wall, the "dam" strengthened by an iron "dam" plate through which the tap hole was made. In the top of the dam was a notch or channel, the slag notch for the flow of the slag. The space between the tymp arch and the top of the dam was kept closed with clay and sand, except when the furnace was at work, save for a hole for the flow of the slag.

The Pig Bed (Fig. 44).—In front of the furnace is a space about 40 ft. by 20 ft., covered to the depth of about 1 ft. 6 in. with a slightly binding sand, similar to the moulding sand used in the foundry, the surface being slightly sloping away from the furnace. As soon as the pigs have been removed, the bed is prepared for the next charge. The sand is levelled, and by means of wooden moulds a series of D-shaped cavities about 3 ft. long, 4 in. wide, and 4 in. deep are made in the sand (see Fig. 44). A boy hammers in the pattern till it is level with the surface, and when he has put in a whole row, he carefully removes them one by one, leaving a row of moulds. Then he cuts channels *b* connecting the ends of these, and these channels in their turn are led into a larger channel *d*, which leads to the tap hole of the blast furnace.

When the furnace is to be tapped, all the cross passages *b*, except the bottom one, are closed by means of iron plugs covered with clay and having long handles attached to them. The metal therefore flows along *d* and fills the bottom series of moulds. As soon as these are full, the second channel *b* is opened and a plug is put across *d* to prevent any more iron flowing down, and this is repeated until all the iron is out. As soon as slag begins to flow, it is directed to the slag

channel, and when the tapping is complete, the surface of
the pigs is covered with sand, or sometimes they are cooled
with water.

Directly the metal is cool enough to handle, workmen,
with their hands protected with pieces of leather, set to
work to remove the pigs. The pigs in the moulds c are
broken from the metal in the channels *b*, the metal being
broken up into pieces of convenient size, and these and the
pigs are at once transferred to stacks, or to railway trucks
for removal. When they are all removed, the bed is prepared
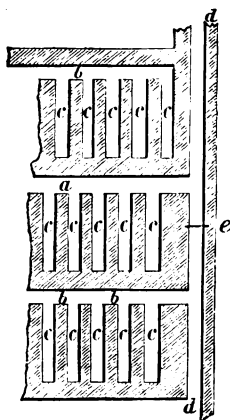
Fig. 44.—Plan of Pig Bed.

for the next charge. The pig bed is usually placed at a con-
venient elevation so that the pigs can be readily loaded into
trucks. Each pig will weigh about 1 cwt., so that for 25 tons,
500 pig moulds will be necessary.

To facilitate the removal of the iron to the trucks,
mechanical appliances are now largely used. In some works
an overhead crane is arranged along the whole length of
the pig bed, and in others a powerful jib crane is run along
the end of the pig bed. As soon as the iron is cool enough,
a lever is put under *b* to raise it a little, a chain is slipped
round or a hook is slipped under, and the grid, consisting
of B with the twenty to twenty-five pigs attached, is carried

bodily away and stacked. When the pigs are required, the grid is again lifted by the crane and taken to a pig breaker, by which the pigs are rapidly broken off. This arrangement saves both time and labour.

Metal Mixers.—In steel making, the iron is required in the molten condition ; it is therefore a waste of time, labour, and fuel to allow the metal to cool, lift the pigs by hand, and melt it again. To avoid this, metal mixers have been introduced.

Fig. 45.—Front of Furnace, showing Pig Bed.

The metal mixer is a large vessel made of sheet steel and lined with refractory firebrick, of such size as to hold from 100 to 500 tons of metal. It is always arranged so that it can be tilted to pour out the metal. One form shown in Fig. 46 consists of a nearly semi-cylindrical vessel resting on rollers, so that it can be easily turned by means of a hydraulic ram. It is provided with two openings, one to receive the metal, the other forming a spout from which the metal is poured. Usually, gas is brought to the ladle so that heat can be applied if there is any danger of chilling. The pig bed is abolished, and in place of it rails are laid at a low level, so that a ladle capable of holding the whole charge of the

furnace (50 or 100 tons) can be run under the tap hole. The metal is run into the ladle ; this is drawn by a locomotive to the mixer, and either by tilting the ladle or running the metal out of a tap hole, the metal is transformed to the mixer, whence it can be poured into another ladle for conveyance to the steel works or use as required.

The mixer has the great advantage in that it gives iron of more uniform quality of metal than can be obtained from the blast furnace direct, because the products from various
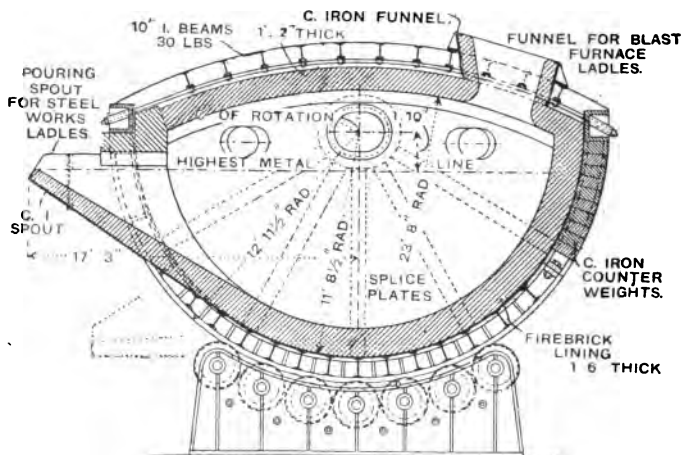
Fig. 46.—Metal Mixer.

furnaces or various taps, being mixed, accidental variations to a certain extent compensate one another.

Casting Machines.—For dealing with large casts of metal, casting machines are used to some extent in this country, and largely in America. Many forms have been designed, but the best known and most largely used is the Uehling. This is used always in conjunction with a mixer, into which the metal is run from the furnace. A series of iron moulds carried on endless chains passes under the mixer at such a rate that each is filled as it passes—the usual rate being about 15 ft. per second. As the moulds pass from before the mixer, they are sprinkled with water to cool the pigs, and as the

endless belt passes over the end pulley, the pigs fall out into a trough of water, whence they are carried by another endless belt at right angles to the first, and delivered into trucks. As the moulds return, they are cooled and prepared for the next charge by being coated with milk of lime sprayed by means of compressed air.

The belt is about 100 ft. long, the moulds are 1 ft. 10 in. by 10 in. by 6 in. deep, and the metal is cast into flat cakes about ¾ in. thick, which solidify rapidly.

Such a machine will handle 1 ton of iron per minute continuously, and the machine will run for months without repair; the moulds last about six months and are easily replaced. Three men work the machine on 12-hour shifts. The average cost of handling a ton of pig iron is said to be 3d. or 3½d. The pigs are perfectly clean and free from sand, but owing to the sudden cooling they tend towards whiteness, and the grade cannot be determined from the fracture. For this reason the machine is not likely to come into use in this country for casting foundry pig.

Hoists.—Hoists, lifts, or elevators are necessary when the loaded trucks cannot be run directly to the level of the charging platform. The more modern plant is generally laid out for some form of the perpendicular lift, but still, as at Barrow-in-Furness and numerous other works, a modification of the inclined plane has been used for raising the ore, fuel, and flux from the ground level to the charging platform. At Barrow the inclined road is carried on a pair of bowstring girders placed at an angle of from 25° to 30° with the horizontal, and the road is fitted with two sets of rails, on one of which the loaded truck ascends, while the empty one descends the other. The carriage consists of a horizontal platform, supported on a triangular frame fitted with two pairs of wheels, of which the front ones are smaller than the back. The lift is arranged so that when the carriage is at the bottom of the inclined plane it is received in a pit in the ground, and its platform is then on a level with the floor of the yard or shed, and the four or more iron wheel-barrows, in which the charge is usually placed for elevation to the furnace top, can be wheeled directly on to the platform; and in like manner, when the lift has made its ascent up the incline, it stands so that the platform of the carriage is level with

the charging platform, and the wheel-barrows can be wheeled directly on to the top. The motive power for this elevator consists usually of a pair of steam engines, working through friction gearing a winding drum about 12 ft. in diameter, around which passes a wire rope, the two ends of which are attached respectively to the ascending and descending platforms, while the action of the engine is controlled by steam brakes.

Of the perpendicular lifts, the water-balance is still in use at some of the older furnaces, where a natural fall of water is obtainable, under which condition it is an economical and simple arrangement, although giving some trouble, owing to the difficulty of keeping the tanks water-tight; whilst if a pump has to be employed in lifting the water to the top of the furnace for introduction into the tanks, its advantages are seriously diminished. In the water-balance arrangement two cages or platforms are employed, beneath each of which is fixed a water-tight tank, capable of containing sufficient water to enable it when filled to draw up the other platform with its empty tank, and the load of ore or fuel. The two cages work between guides, and are respectively suspended from the extremities of a wire rope passing over guide pulleys. Thus, when one cage is at the furnace platform, and the other at the ground level, the tank of the latter is emptied of its water through a valve fitted in the bottom of the tank, while the tank of the former is filled with water. In this manner sufficient weight is added to the top cage to draw up the other cage with its load of charging materials from the bottom to the top of the lift.

Pneumatic or compressed-air lifts are sometimes employed in which the areas of the pneumatic cylinders are adjusted so that a pressure of from $3\frac{1}{2}$ lbs. to 6 lbs. or 7 lbs. per sq. in., as occurs in the blast-main supplying the blast furnaces, is sufficient to elevate the required load. In other arrangements, double-acting air pumps by which air is forced into or withdrawn from the cylinders as required, are employed. In pneumatic lifts compressed air or the atmospheric pressure working against an exhaust is used. The best known of these is that of Mr. Gjers (Fig. 47). In this the platform surrounds a circular tube about 3 ft. in diameter, and is attached, by means of wire ropes working

over pulleys, to a piston working in the tube. To raise the platform the air is exhausted from behind the piston and the pressure of the atmosphere forces it down. To bring the platform down, air under a pressure of about 2 lbs. is forced beneath the piston.
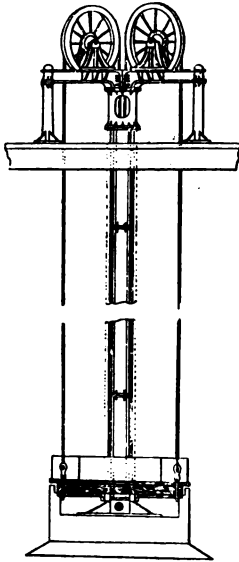

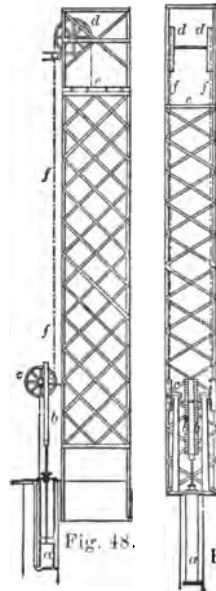Fig. 47.—Gjer's Pneumatic Hoist.

Figs. 48 and 49.—Hydraulic Hoist, Side and End Elevations.

In hydraulic lifts, or hoists, a ram, actuated by pressure from a hydraulic accumulator, is connected with a chain and system of pulleys whereby the movement of the load to be lifted is some six or eight times greater than that of the ram by which it is actuated, according to the multiplying powers of the chains and pulleys employed. Figs. 48 and 49 show a simple form used in America; the ram of a hydraulic cylinder *a* terminates in two racks *b*, which gear into two pinions on the same axle as the pulleys *c*, round which the wire rope *f* passes from the table *e* over the guide pulleys *d*, so that

by properly proportioning the diameter of the pinion into which the rack gears, to that of the pulleys or drums c, any desired velocity of ascent can be given to the cage.

Direct-acting steam hoists are now generally used. The cage works in guides like an ordinary colliery cage, and is provided with safety catches to prevent accident ; the cage is supported by a wire rope which passes over a large pulley and then round a drum worked directly by an engine.

For each ton of iron obtained from, say, Cleveland ore, about 4 tons of material will need to be lifted ; or for a furnace making 50 tons a day, about 200 tons in addition to the weight of the cage, which has to be lifted each time. Assuming two tons to be carried each time, the lift must make 100 ascents per day for each furnace.

Blowing In.—Before blowing in, or putting a furnace into blast, the masonry of the structure must be thoroughly and slowly dried to prevent cracking or fissure of any portion of it. Then the tuyere holes are built up, and a quantity of rough old timber introduced into the furnace, sufficient to fill the hearth to a depth of 5 ft. or 6 ft., and on this sufficient coke is placed to fill the boshes. The timber is then ignited, and the combustion rapidly extends to the coke above it, when successive layers of coke and limestone are introduced, until the furnace is about one-third filled, the limestone serving as a flux for the ashes of the coke. This charge is followed by light burdens made up of about three parts of calcined ore, with one part of limestone and two parts of coke, thus gradually filling the furnace up to the throat. Then blast-tuyeres of about one-half the diameter of those to be eventually used are inserted, and the blast put on at about one-fifth of the normal working strength. This condition is continued for from thirty-six to forty-eight hours, after which the blast nozzles are changed for others of ¾ in. or 1 in. greater diameter, which deliver a proportionately larger blast ; at the end of twenty-four hours tuyeres larger by a further ¾ in. in diameter are inserted ; and a further increase of ½ in. in diameter is made to the blast nozzles at the end of about the third week. But it is not until some four or five weeks after the first introduction of blast that the full working pressure and volume of blast are employed, and in the interval

the furnace is run on light burdens which are increased with each increase in the strength of the blast.

Slags first appear twelve hours after the admission of blast to the furnace, but there is no metal until the end of twenty-four hours ; then it collects slowly and is tapped out as is necessary, but it is only after three or four days that the metal can be tapped from the furnace at regular intervals. When Cleveland furnaces are in regular blast the charge takes about seventy-two hours to pass from the top or charging plates to the hearth, but in some of the small furnaces, or where the driving is rapid, the time is much less.

The furnace having once been put into blast, continues at uninterrupted work until it is necessary to stop for repairs or some other cause. When, owing to a temporary scarcity of ore, fuel, or the like, it becomes necessary to stop the working for a short time, the throat and tuyere holes are closed with sand or clay, under which conditions the furnace may stand for three or four days without much danger ; but if such delays are prolonged for one week or upwards, then troublesome obstructions are likely to form within the furnace, perhaps necessitating entire stoppage. A well-built blast furnace will run, under ordinary working and driving, for five or ten years without requiring to be blown out for repairs, but with the rapid driving now becoming general the life is very much shorter.

Blowing Out.—When a blast furnace is to be stopped—blown out—the burden is gradually reduced so as to increase the working temperature, and facilitate the fusion of any obstructions hanging within the furnace. The tubes and fittings from the throat are then removed, charging is discontinued, and the furnace allowed to burn itself down, care being exercised to take the last tapping of metal from the lowest possible point in the hearth. After blowing out a furnace which has been long in blast, there is often found in the bottom of the hearth an agglomerated mass of malleable steely-iron known as " bear " or " horse," and similar but smaller masses will be attached to various points around the sides of the hearth. These masses contain besides iron, also manganese, carbon, silicon, and copper, as also nickel, cobalt, and occasionally traces of the rarer metals, and sometimes copper-coloured crystals of a nitro-cyanide of titanium.

Scaffolds, etc.—Scaffolds are obstructions in blast furnaces which arise from various causes, such as the faulty distribution of the charge, which prevents the regular descent, whilst, as the charge below the scaffold is working down, the mass above is left with a diminishing support, and the weight of superincumbent materials is at the same time constantly increasing by the addition of fresh materials at the furnace mouth. In these circumstances the obstruction at a certain point frequently gives way suddenly, and descends with considerable force to the hearth, constituting what is known as a " slip." When a scaffold is discovered, the blast is eased so as to reduce the support from below due to the pressure of blast, and efforts are made to get down the scaffold without any sudden rush. Scaffolds also sometimes lead to the formation of a slight skew-back in the lining of the furnace owing to the erosion of the lining for some distance up, the effect of which is that a part of the stock or charge is held up, while other parts slide over it, and the furnace is thus found to work slowly and affords a diminished yield of metal. But scaffolds of the last class usually fill up with finely divided fuel and ore in good condition for rapidly melting, so that, after working for some time in this condition, the heat and attrition of the descending charge will work off the irregularity in the lining, and the materials of the scaffold will then work down quickly into the hearth, giving a much larger temporary yield to the furnace. A scaffold obstructs the free passage of the blast and the escape of the furnace gases, and tends to cool down the furnace and so thicken the slags. A slip, especially if the ore is very wet, may cause an explosion by the sudden evolution of steam as the wet material comes into the hot region of the furnace.

Amongst the causes contributing to the formation of scaffolds are: (*a*) faulty shape of the furnace; (*b*) the production of an imperfectly fusible slag; (*c*) too large a proportion of refractory ore in the charge; (*d*) bad fuel, such as a weak friable coke which crumbles away under the weight of the superincumbent materials; and (*e*) faulty charging, whereby the regular distribution of heat over the entire horizontal section is not maintained, owing to the larger pieces of coke collecting round the walls of the furnace, whilst the small and impermeable ore is concentrated in the centre.

CHAPTER IX.

BLOWING ENGINES.

A VERY large quantity of air is required for the blast furnace, and this must be supplied in a steady, continuous stream, and at a suitable temperature and pressure. In the early, very small furnaces, bellows worked by water power were at one time used, but these have been completely superseded by cylinder blowing engines driven by steam, gas, or water power.

Such an engine, as far as the blowing portion is concerned, consists of a cylinder, closed at both ends, in which works a piston. The cylinder is provided with two sets of valves at each end, one set opening to the air to admit the air from outside, and the other to allow the air to pass into the air mains, and called respectively the intake and outlet valves.

A few large cylinders or a large number of small cylinders may be used, according to convenience. In the older engines the tendency was to use a few large cylinders; now the cylinders are usually made smaller, and a larger number is provided.

Amount of Air Required.—The amount of air required can be easily calculated. One pound of carbon will require for its combustion to carbon-monoxide—and this is the conversion which takes place in the blast furnace—5·8 lbs. of air, or, as 1 cub. ft. of air under the normal conditions of temperature and pressure weighs ·0809 lb., 65·5 cub. ft. As the air will always contain moisture, and will usually be at a higher temperature than 0° C., it is often assumed that each pound of carbon will require 6 lb., or 76 cub. ft., of air, and these figures will be quite near enough for ordinary rough estimations. It must, of course, be remembered that the volume of a gas varies very much with changes in temperature and pressure, so that for the combustion of the same quantity of fuel a greater volume of air will be required when the temperature is high than when it is low, and also that as water vapour is much lighter than air, the weight of a cubic foot of ordinary moist air will be less than that of a cubic foot of dry air.

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Assuming 5·8 lb. or 65·5 cub. ft. to be a correct estimate, this will be 5·8 tons, or about 147,000 cub. ft., for each ton of carbon consumed. Assuming the coke burnt to contain 90 per cent. of carbon, 5·22 tons, or 132,000 cub. ft., of air will be required for each ton of coke consumed.

The effect of moisture in the air will be to increase the quantity of air required, because the volume of water vapour required to burn a given weight of carbon is just twice the volume of the oxygen required for the same purpose, and also because, water vapour being lighter than air, the density of the mixture will be less than that of the dry air. The effect of moisture in reducing the temperature in the furnace has already been mentioned.

Blowing Cylinder.—The blowing cylinder for the supply of air is sometimes placed vertically and sometimes horizontally, the former being the more general. In the older type of blowing cylinders (Fig. 50) the intake valves were placed at the bottom and at the top, those at the bottom being small rectangular metal plates faced with leather or indiarubber, working on horizontal valve seats in the bottom cylinder cover, and held in place when closed by gravity. On the top cover valve boxes were usually fixed in which the valves hang nearly vertically, and work against valve seats in the boxes.

Fig. 50.—Blowing Cylinder, Section.

In many modern engines gravity valves are replaced by valves closed by a spring, and these are often arranged in a ring round the ends of the cylinder, which is lengthened at each end beyond the travel of the piston ; and in some recent engines slide valves have been successfully used. The outlet valves by which the air passes to the air main are as a rule similar to the intake valves, but they have a much smaller area.

Beam Engines.—The early blowing engines were all of the

"beam" type. As a rule, the two cylinders are equidistant from the support so that the stroke is the same. Owing to the weight of the moving parts and the slowness of the motion, a flywheel is almost always used, this being attached by a connecting rod to the beam at a point near the steam end, or to a horn or projection at the end of the beam beyond the steam cylinder; these were called hornbeam engines. In the
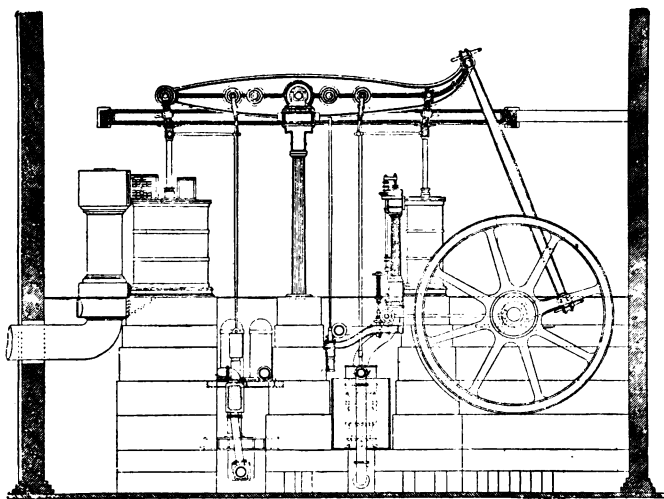

Fig. 51.—Beam Blowing Engine.

first erected the beams were of wood, but cast-iron was soon substituted, and the engines were much increased in size.

The beam blowing engine (Fig. 51) is very strong and durable, there being many at work to-day which have been running for fifty years. They can only be worked at a low speed—50 or 60 strokes per minute—and therefore the cylinders are made of large size, those of the famous Ebbw Vale engine being 12 ft. in diameter, and having a stroke of 12 ft., whilst 10 ft. in diameter and 10 ft. stroke is a common size. Frequently two such engines are placed side by side and coupled together.

Direct-acting Engines.—The beam engine is very

cumbersome, and it was soon suggested to replace it
by a direct-acting engine in which the cylinders were
placed in line either vertically or horizontally, and the
pistons were attached to the same connecting rod. For
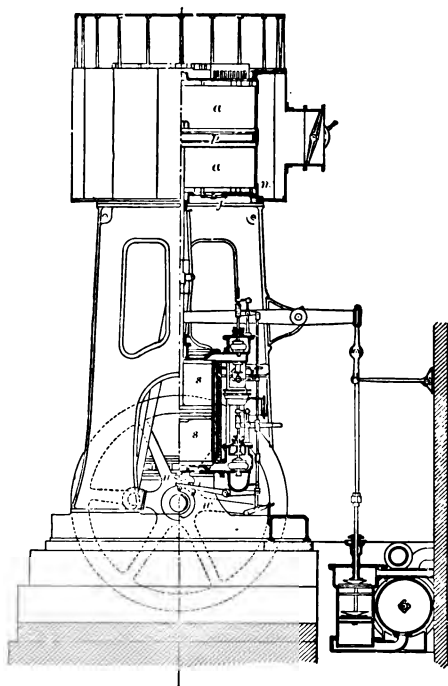blast furnace work, the vertical type is almost always

Fig. 52.—Blowing Engine, Elevation half in Section.

used   The cylinders of these engines are usually made
very much smaller than those of beam engines, common
sizes being 6 ft. diameter and 6 ft. stroke, and 5 ft. diameter
and 5 ft. stroke, but they are driven at a considerably higher
speed. The arrangements vary very much as to detail.
Sometimes the blowing cylinder is placed at the top,
and sometimes the steam cylinder. The flywheel is some-

times attached to a crosshead on the piston rod between the cylinders, or it may be attached to the lower end of the piston rod, which in this case is made to pass through the lower cylinder cover, by means of a connecting rod. The vertical direct-acting engine is the form now most generally used in British ironworks. Fig. 52 shows such a blowing engine half in section.

Double or triple expansion engines, with two or three cylinders, the steam passing from one to the other, are also used.

Fig. 53.—Pair of Quarter Crank Blowing Engines, as Fitted in Shop before Sending to Works.

The Quarter-crank Engine.—An engine built by Messrs. Richardsons, Westgarth and Company (shown at Fig. 53), and known as the quarter-crank engine, is coming largely into use. In this engine the steam and air cylinders are placed side by side and are connected by connecting rods to cranks on the same driving shaft, the flywheel being placed between the cranks. The cranks are not placed in line, but one a little in advance of the other, so that the two pistons do not reach the dead point at the same time.

Gas Engines.—One of the most recent innovations is the adoption of gas-driven engines for blowing purposes (Fig. 54). In the gas or internal combustion engine a mixture of a combustible gas and air is admitted to the

working cylinder, and is there ignited, the expansion of
the gas produced by the heat of the combustion drives the
piston forwards, so that the heat of the gas is utilised directly,
and not by way of the generation of steam.   At first, gas
engines were built only of small size, and were driven by rich
gas, such as coal gas ; but gradually they have been increased
in size, and designed for the use of poorer gas, such as ordinary
blast furnace gas ; and engines up to 1,000 h.p., driven by
blast furnace gas, are now in regular use.   The gas engines
are usually built horizontal, and the gas must be thoroughly
washed so as to be free from tar and dust.

Turbine Engines.—Parsons' turbine (Fig. 55) has been
ntroduced as a blowing engine, a steam turbine driving a

Fig. 54.—1,500-h.p. " Cockerill " Type Blowing Engine, with Double
Acting Gas Cylinder.   (Richardsons, Westgarth and Co.)

turbine blower.   Engines of this type have now been fitted
at several works.   They are said to be very economical, and
they give a much steadier blast than any type of piston
engine, and they also occupy much less space.

Blast Regulation.—With any form of cylinder blowing
engine the air will leave in puffs instead of in a perfectly
uniform stream, owing to the varying speed of the blowing
piston.   To overcome this difficulty and to send the air for-
ward in a steady stream, blast regulators were attached to
the main.   These usually consisted of large balloon-shaped
vessels of sheet-iron having a capacity about equal to or a little
less than the blast delivered per minute.   The mass of air
in the regulator has sufficient elasticity to take up the varia-
tions in pressure, being compressed when the pressure rises
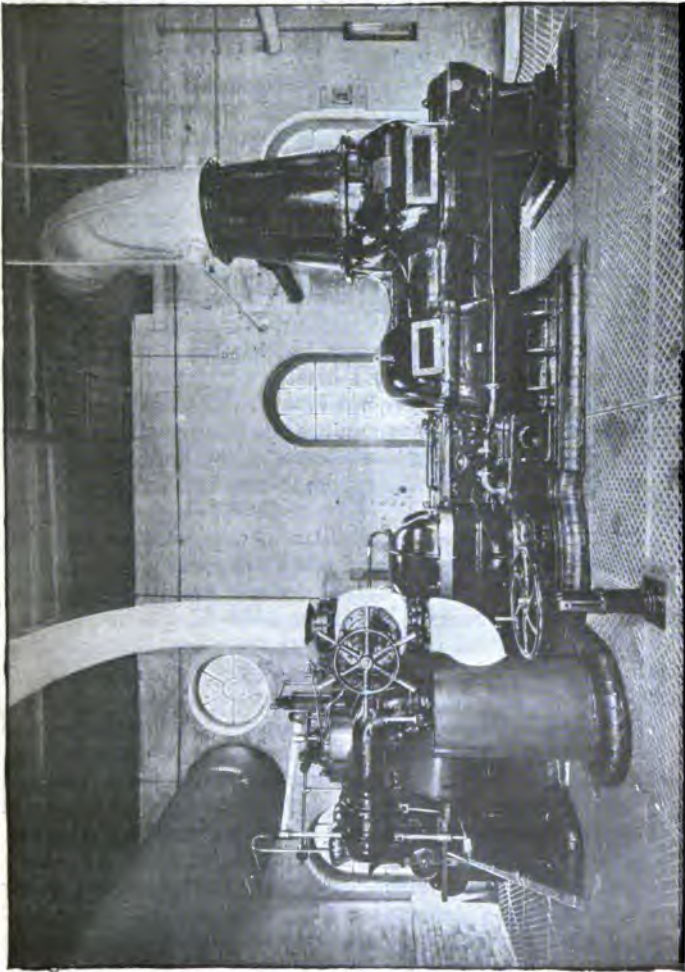and expanding again as it falls.   With modern plant no blast

Fig. 55.—Parsons' Turbo-Blowing-Engine Capacity = 18,000 cub. ft, of air at 3,000 revolutions per minute.

regulator is necessary, the large mains and hot blast stoves containing enough air to act as regulators.

Arrangement of Engines.—In Great Britain, as a rule,

either one large engine is used to supply the air, or two or more, are attached to the same blast main. This method has the advantage of simplicity, but the great disadvantage that all the furnaces must be blown with the blast at the same pressure. In modern works, especially in America, each furnace is provided with its own engines, usually three, these being worked in pairs, and the third standing by for use in case of emergency. This system has the great advantage that each furnace can be given a blast pressure suited to its needs. This system will certainly become general as new works are erected or older ones are remodelled.

The Mains.—The size of the mains must be sufficient to carry the air with but little friction, and obviously, since air expands very much when it is heated, the hot blast main must be larger than the cold blast, and many failures have arisen from neglect of this precaution. The cold blast main carries the gas to the stove, and the hot blast from the stove to the furnace. The gas main takes the gas from the furnace top to the recovery plant, if there is one, and then to the hot blast stove.

Pyrometers, etc.—A pressure gauge, preferably self-recording, should be provided near the furnace so that the foreman may observe the actual working pressure at the furnace and its variations. Pyrometers should also be provided by which the actual temperature of the blast may be taken. Both pressure and temperature may vary very much during the day.

Blast Pressure.—The pressure of the blast must be sufficient to force the air through the furnace at the rate desired. For small charcoal furnaces the pressure may be as low as $\frac{1}{2}$ lb. per square inch. Ordinary Scotch furnaces with an output of about 300 tons a week use a blast pressure from $3\frac{1}{2}$ lbs. to 5 lbs., whilst in many modern furnaces a pressure of 11 lbs. or more is used. The engines must, of course, be capable of steadily maintaining the necessary pressure, and should be capable of giving more in case of emergency. Many modern blowing engines are capable of giving a pressure of 22 lbs. or more, but they are not worked regularly at the full pressure.

CHAPTER X.

HEATING THE BLAST.

THE introduction of hot-blast instead of cold-blast was attended with an economy in fuel and an increased make of iron by the furnaces, as already stated. A temperature of 1,500° F. (815° C.), or a visible red heat, is now commonly employed. But in the production of these higher temperatures the stoves of the older type, with cast-iron pipes, are rapidly destroyed, and other stoves constructed upon the regenerative principle of Sir W. Siemens are always used. The first attempts to heat the blast were made by passing the air through iron boxes or pipes heated by separate fires.

U-Pipe Stove.—The first successful form of pipe-stove or oven consisted of a series of eight or twelve parallel arched pipes or tubes of cast-iron, of circular or elliptical section, arranged in an oblong chamber of fire-brick, along the sides of which were two circular mains fitted with sockets, into which the legs of the vertical pipes were fitted, while between the mains, and running the full length of the stove, was a rectangular fireplace. The cast-iron pipes were ∩-shaped, and stood vertically in the stove, with one foot in a socket upon the horizontal main running along one side of the furnace, and the other foot in a corresponding socket upon the main on the other side, and so the tubes spanned across the fireplace ; for this reason it was called the U-pipe stove. There were stops or partitions in the horizontal main, so that the cold blast from the blowing engines, entering at one extremity of the one main, ascended from it through one set of ∩ pipes passing across the stove, and then back again by the next set, and so on to the other end of the stove, the cold air thus passing several times over the fire before it left the stove by the hot-blast main to the furnace.

The pipes at first were heated by burning fuel upon the rectangular central fire-grate, but later burning blast furnace gas along the median line of the stove. In each case the flame and heated gases passed between and around

the stove-pipes, thus heating them on the exterior,
and the products of combustion finally escaped from
a chimney in the dome or roof of the stove. The better to
absorb the heat, the stoves were sometimes divided into two
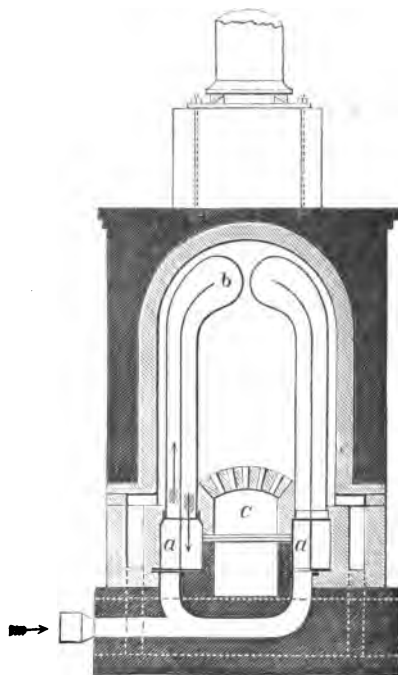chambers, by a partition wall reaching from the floor almost to

Fig. 56.—Pistol-pipe Hot-blast Stove, Vertical Section.

the roof, so that the flame and gases first circulated through one
half, and then passed over the division wall, and through the
second half of the stove, before escaping by the chimney.
The stove-pipes frequently broke by their own contraction and
expansion as the temperature varied, and to mitigate this,
a suggestion was made to place one of the horizontal mains
upon rollers, so that it was free to move inwards or outwards
with the expansion and contraction of the legs.

Pistol-pipe Stove.—The pistol-pipe stove is another form of the cast-iron pipe arrangement used for some of the furnaces in Cleveland, Scotland, France, and Germany. In this stove (Fig. 56) the two legs of the pipes in the previous arrangements are replaced by a single pipe, divided, as shown, by a septum or dividing rib, *b*, reaching from the mouth almost to the top or closed end of the pipe, and so practically dividing each pipe into two tubes. The closed end is enlarged slightly and bent over somewhat, so that its form bears some resemblance to the stock of a pistol, hence the name. When the stove is heated by solid fuel, these pipes are arranged on each side of a rectangular fireplace, *c*; and the pipes on each side of the stove lean over towards each other, so as almost to come into contact; thus the cold air enters at the bottom of the stove into one division of the box *a, a,* in which the pipes stand, and, since these are divided into compartments by divisions corresponding to those in the pipes, the air or blast ascends in succession through one side, as shown by the arrows, and descends along the other side of the division in each pipe, until it finally passes out from the end of the stove to the hot-blast main, and thence to the furnace.

The heating surface supplied by pipe-stoves is usually calculated so as to allow about one square foot for each cubic foot of blast passing through the pipes per minute, if the stoves are fired with coal, or about 10 to 20 per cent. more if fired with the waste gases. Many other forms of pipe stoves were introduced at various times, but none of them is now in use, having been completely displaced by the modern fire brick stoves on the regenerative system.

The use of cast-iron pipe-stoves was attended with serious loss and inconvenience, arising from the frequent fracture of the pipes due to the repeated alternations of temperature to which they are subjected, and to the expansion and contraction of the pipes during the working of the stoves. A further cause of fracture is the rapid oxidation and destruction of the pipes at the high temperatures.

FIRE BRICK STOVES.

Cowper Stove.—Of the fire brick stoves, the Cowper stove, invented by Mr. Cowper, of Middlesbrough, was

the first. It consists of an outer wrought-iron casing (Figs. 57 and 58), lined internally with several rings of fire-brick, built in half-brick courses, the stove being closed by a dome-shaped roof, also lined with fire-brick. Within this casing is built up a circular fire-brick combustion chamber, *m*, at the base of which are the inlet valves G, for the gases from the blast furnace and the valve A, admitting the air
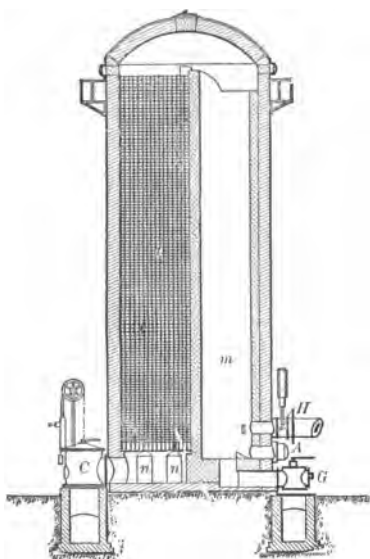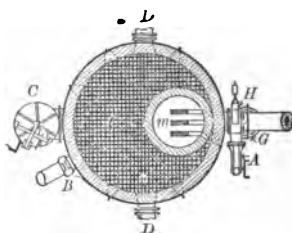

Fig. 57.—Cowper Hot-blast Stove,
Sectional Elevation.

Fig. 58.—Cowper Hot-blast
Stove, Plan.

necessary for the combustion of the gases ; whilst H is the outlet valve for the hot-blast. The body of the stove is filled by the regenerators or fire-brick chequer work *t*, at the base of which are the cold-blast valve B, and the chimney valve C, while at D, D are the cleaning doors. Placed at intervals over the bottom of the stove are dwarf pillars, *n*, of brick or iron, which carry short girders upon which rest a series of strong grids, which support the regenerators In the original form of stove the regenerator bricks were 2 in. thick, 5 in. wide, and 12 in. long, and were arranged

so as to leave vertical open passages about 4 in. square through the entire height of the stove—that is, from the grids at the bottom to within a few feet of the domed top of the stove. When the chimney-valve c is open, gas and air are admitted at the bottom of the combustion chamber by the valves g and a respectively ; the gas immediately ignites and is split up into three currents by the divisions shown in Fig. 58 ; thus a more complete mixture of the air and gas is effected, and an immense flame ascends through the flame flue, spreading out beneath the dome over the top of the regenerators. The flame and heated products of combustion then pass slowly to the bottom of the stove, through the numerous square passages in the chequer work, before they escape by the chimney flue. In this manner the mass of brickwork within the stove, absorbing heat from the incandescent gases in contact with it, attains to a very high temperature, the upper layers of brickwork naturally becoming hotter than the brickwork near the bottom of the stove, while the products of combustion are reduced in temperature as they descend through the stove and finally pass out by the chimney flue c, at a temperature of about 400° F. (240° C.).

The stove having thus been heated by the combustion of the blast furnace gases within it, and by the passage of the products of combustion through it, the gas-valve g, the air-valve a, and the chimney-valve c are all closed, while the cold-blast valve b at the bottom of the stove is opened, as is also the hot-blast valve h near the bottom of the flame flue. The cold air then enters the stove at the lower or cool end of the regenerator, and slowly ascends through the height of the stove along the small but numerous passages of the regenerator, and from thence down again through the combustion chamber, and so out by the hot-blast valve h to the blast main and thence to the furnace tuyeres. The cold air thus traverses the stove in exactly the reverse direction to that followed by the gases in heating the stove, whereby the cold blast slowly takes up the heat given out by the brick surfaces of the stove, and the blast is quickly raised to a temperature of 1500° F. (815° C.) or redness. Since the blast first enters at the lower or cooler part of the stove, it is gradually heated to the above temperature without materially
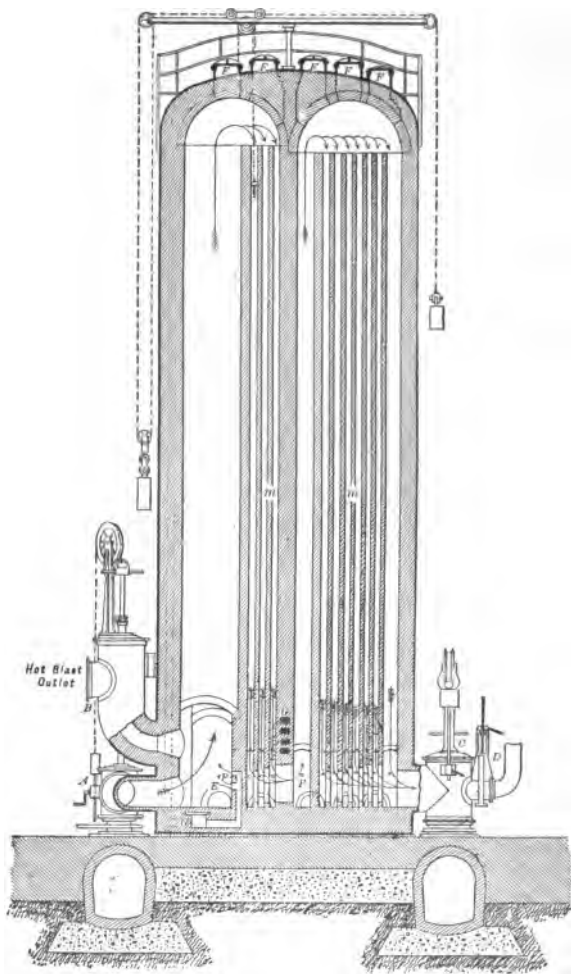
Fig. 59.—Whitwell Hot-blast Stove, Sectional Elevation.

cooling the upper layers of brickwork in the regenerators, before the lower parts have lost much of their heat, and in

this manner the stove affords a fairly regular temperature, the upper part never falling below redness.

Two stoves are worked in conjunction, so that whilst one stove is being heated by the combustion of the blast furnace gases, the cold air is being driven through the other and heated to the temperature required for the blast furnace. Two stoves are necessary for one furnace, but three stoves can be made to serve two furnaces. The main from the stoves to the furnace is usually made about 3 ft. in diameter, and is lined with a 9-in. course of fire-brick to prevent cooling and corrosion.
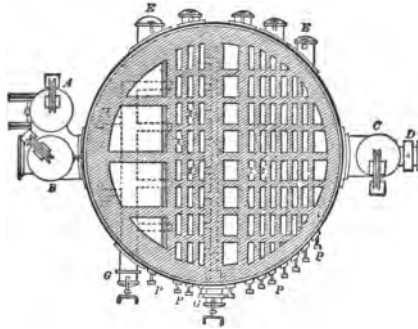
Fig. 60.—Whitwell Hot-blast Stove, Sectional Plan.

In the modern Cowper stoves bricks of special form are used so as to give a series of vertical passages and thus give no facilities for the lodgment of dust. Cowper stoves are from 50 ft. to 75 ft. high, and from 20 ft. to 25 ft. in diameter, the larger stoves having about 75,000 sq. ft. of heating surface.

Whitwell Stove.—The Whitwell stove differs from the Cowper principally in the arrangement of the heating surfaces, which in this case consist of broad spaces and flat walls. The air is often admitted at several points, so that the combustion of the gases first entering the stove is only completed after they have traversed partly through the stoves.

The Whitwell stoves have been built in England up to 68 ft. in height, by 22 ft. in diameter, and containing 26,000 sq. ft. of heating surface ; while in America they are working

as large as 70 ft. in height and 21 ft. in diameter, with a heating surface of 30,000 sq. ft. These stoves (Figs. 59 and 60) have an outer shell or casing of wrought-iron plates, lined internally with fire-brick, while, to permit of the expansion and contraction of the lining, there is left a space of 1 in. between the iron casing and the lining, this being usually filled in with granulated slag. Within this cylindrical chamber is built a series of long narrow vertical walls forming chambers, m, communicating with each other at the top and bottom. The partition walls nearest to the point where the blast furnace waste gases first enter become hotter than the rest of the stove, and are built thicker than those near to where the gases make their exit.

The gases from the blast furnace enter the stove through the valve A, fixed on the side of the stove casing, and, meeting immediately with the air passing from the air-valves (also fixed to the external casing) through the air-courses G, combustion at once ensues, and the incandescent gases rise to the top of the chamber, distribute themselves over one or more walls, as indicated by the arrows, and descend through one or more smaller chambers towards the bottom of the stove, the gases imparting their heat to the fire-brick walls as they pass over their surface. A further supply of air is admitted, and mixes with the gases at the bottom of the stove ; here more complete combustion ensues, and the products re-ascend either by another wide combustion chamber or, in the older designs, through two or three of the narrow chambers, and finally descend through the remaining chambers to the chimney-valve C, from whence the gases pass away to the chimney at a temperature of from 300° to 400° F. (149° to 204° C.). The communications between the several chambers, through which the gases pass at the top and bottom, are placed so as to cause them to travel as much as possible towards the sides of the stove, and so render the total heating surface as effective as possible. In the casing of the stove, and opening through the lining, are a row of eye-pieces, P, opening into the several chambers, so that the state of the stove may be observed, and the combustion of the gases regulated accordingly.

In the latest Whitwell stoves the products of combustion leaving the combustion chambers distribute themselves over

the whole of the passages and pass downwards to the flue, the gas passing therefore only once down the stove. When the stove is sufficiently heated, which happens after a lapse of from one to two hours, the gas-valve is closed, and then the chimney and air-valves are also closed, while the cold-blast valve D, and the hot-blast valve B, are opened, whereby the blast enters the stove at its coolest part, and traverses the chambers in the reverse direction to that pursued by the gases in heating up the stove. The heated blast finally leaves the stove by the valve B, to the hot-blast main, and it has then an average temperature of 1400° F. (738° C.) to 1500° F. (815° C.). One stove is alternately heated up by the combustion of the waste gases, and is then employed in giving up its heat to the blast forced through it, and if these reversals or changes are made at sufficiently small intervals to prevent the hotter end of the stove from falling below redness, it is assured that the gases always ignite immediately they enter the stove, and the temperature of the blast is kept more regular.

The Whitwell stoves are provided with doors, F (Fig. 59), at the top, through which scrapers can be introduced for raking and cleaning out the dust from the walls; the dust, etc., so collected on the floor of the stove being afterwards removed through the six side cleaning-doors E (Fig. 60), at the bottom of the stoves. This operation of cleaning occupies from eight to ten hours, but can be effected whilst the stove is still at a red heat, and requires repeating every two or three months.

The Massick and Crookes stove resembles that of Whitwell, but is claimed to afford greater facilities for cleaning. The combustion chamber is in the centre, the heating chambers being around it, the gas traverses the stove three times.

The Ford and Moncur Stove.—This (see Figs. 61 and 62) is now one of the most popular stoves, and is largely replacing the earlier forms. It differs from the others in several respects. The combustion chamber extends right across the stove, thus dividing it into two heating chambers, one on each side, each of these being again divided into two by a cross wall, so that there are four distinct heating chambers; and each of these is provided with its own set of valves, and any one can be " cut out " if necessary.

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The heating chambers are divided into narrow passages by a series of parallel walls, and these are crossed by a large number of lozenge-shaped bricks placed with the sharp edges upwards and arranged so as to " break joint." A chequer work is thus formed, which is very strong, offers a large heating surface, and does not accumulate dust. Across the upper part of the combustion chamber arches are built which carry walls dividing it into passages so as to help the absorption of heat. The gas and air enter the combustion chamber where they are burned, and the products spread over the heat-
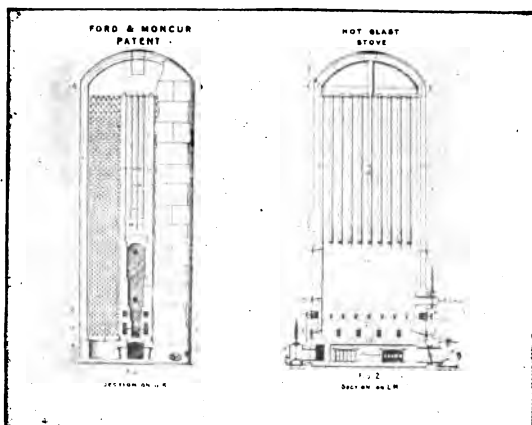
Fig. 61.   Fig. 62.

Figs. 61 and 62.—Ford and Moncur Stove, Sections at Right Angles to and through the Combustion Chamber.

ing chambers and descend to the flue. The heating surface is very large, a stove 72 ft. high having about 64,000 sq. ft.

Valves.—The stoves must be provided with efficient valves. The cold air valve usually opens to the outer air; it is provided with a cover, by which the amount of air admitted can be regulated. The cold blast valve may be an ordinary disc valve, but the hot blast valve, being subject to great heat, is always made hollow, and is kept cool by the circulation of water or air.

Cleaning Stoves.—A considerable quantity of dust is

carried over into the stoves, and the air current, being slower than in the mains, a good deal settles out, and it is very important to allow no places for the lodgment of this dust. Dust-catchers keep back some of the dust, but not by any means all. Cleaning doors are provided, which can be instantaneously opened.. The cold blast is sent in, all the valves are closed, and the air, expanding by the heat, exerts considerable pressure; then the doors are suddenly opened, and the dust is blown out.

In the older forms of stove, where the dust found ready lodgment on the bricks, it was common to explode a small charge of powder or fire a gun into the stove to shake down the dust. Often cleaning holes are provided in the roof by which wire brushes can be passed down the passages; and sometimes the stoves are built on columns with cleaning doors at the bottom, so that brushes can be put upward, this being always done when the stove has been for some time on air, so that the bottom is comparatively cool.

Size and Number of Stoves.—Stoves are now built up to 80 ft. high and 25 ft. in diameter. In this country, usually all the stoves are in connection with the same main, so that all the air supplied to the furnaces is at the same temperature. As the stoves are worked in pairs, at least two must be used, and in general there will be some multiple of two, unless, as is often the case, an additional one is provided to allow for repairs. In general, two stoves should be provided for each furnace, but in many works the number is less, whilst in some recent works four stoves are provided per furnace. In the best modern practice each furnace has its own pair of stoves, an additional one being provided to allow of repairs.

The amount of heating surface required varies with the temperature of the blast. For a large output and a very hot blast Mr. Stevenson gives 444 sq. ft. of heating surface for each ton of iron produced in twenty-four hours.

Equalising Temperature of the Blast.—With fire-brick stoves, which are usually reversed every hour, there must be a variation in temperature, the blast being hottest when the stove is first put on, and falling gradually. With a blast at 1,300° or 1,400° F. (700°–760° C.) the fall of temperature during the run will be about 200° F. (110° C.). This can, to some extent, be prevented, the temperature being reduced to

the lower point by admitting a regulated and diminishing quantity of cold air to the hot blast main. This is, however, troublesome. Messrs. Gjers and Harrison have recently suggested the use of an " equaliser," which is simply a large hot blast stove, so placed that the hot air from the stoves on its way to the furnace passes through it. Thus the variation in the blast temperature is reduced to a very small amount.

Use of Dry Air.—For a large output it is essential that the temperature at the bosh of the furnace should be kept as high as possible. If the air blown into the furnace contains— as it always does—water, this is decomposed thus : $H_2O + C = CO + 2H$, yielding hydrogen and carbon monoxide. The carbon burning to carbon monoxide will evolve the same amount of heat as if it were burnt by air ; but each 9 lb. of water decomposed, liberating 1 lb. of hydrogen, will absorb 29,000 units of heat. This can only be prevented by using dry air. The air is, of course, not dried by heating, the term " dry " commonly applied to hot air not meaning that it is dry in the true sense of being free from moisture, but merely that it can take up a larger quantity, and therefore seems dry. The only way to dry the air is to cool it, so that the water which it holds is precipitated in the solid form. Mr. Gayley has suggested that the air should be dried before being passed to the hot blast stoves. He passes the air through refrigerating chambers consisting of iron pipes through which brine cooled below 0° C. is made to circulate so that the moisture in the air is precipitated. Not only is the quantity of moisture in the air considerable, but it is constantly varying, and in the case of Pittsburg Mr. Gayley has calculated that for a furnace using 40,000 cub. ft. of air per minute, from 73 to 237 gallons of water are carried into the furnace per minute, according to the condition of the air. The use of dry air, he contends, increases and equalises the output, and reduces the consumption of fuel. Against this has to be set the cost of the refrigerating plant, and whether the method will be profitable remains to be proved.

Temperature of the Blast.—The blast is now generally used at a temperature of about 1,400° F. to 1,500° F. (760° C. to 815° C.). The temperature should always be taken and recorded by a pyrometer placed in the hot blast main as near as possible to the furnace.

CHAPTER XI.

WORKING THE BLAST FURNACE.

CHARCOAL burns very readily, and owing to its being very porous gives a very high temperature at the tuyeres. It is so easily crushed that only small furnaces can be used. Charcoal, being free from sulphur, produces a superior pig-iron; but, owing to its cost, furnaces employing it are almost extinct. Even in Sweden, charcoal has been superseded by coke. From 21 cwts. to 22 cwts. of charcoal are required per ton of pig produced.

Coke is the chief fuel employed in iron smelting, and in selecting the best coke, regard should be paid to its freedom from ash and its power to resist a crushing pressure. A hard coke, yielding but a small proportion of ash matter, is preferred. The hard, compact coke employed in the Cleveland district contains from 4 per cent. to 10 per cent. of ash, and from 0·25 per cent. to 1·0 per cent. of sulphur; and an average of from 20 cwts. to 22 cwts. of it is consumed in the production of one ton of No. 3 grey foundry pig from Cleveland ironstone, yielding, after calcination, about 46 per cent. of metallic iron; and about ½ cwt. under or above these figures is required respectively for the production of a number under or above No. 3 pig in quality. Thus, if 20 cwts. of coke be required for the production of No. 3 pig-iron, then 20½ cwts. will be necessary for the production of one ton of No. 2.

The coke may be made either in Beehive or recovery ovens. At one time there was a prejudice against the latter, but that is now dying out, and most of the large works recover the by-products in the manufacture of the coke.

Coal is only used in localities where suitable coals occur. It must be of the non-caking variety, as free as possible from sulphur, and should afford but a small percentage of ash;

Caking coal has a tendency to collect into lumps, and so to obstruct the passage of the gases.

Raw coal is used only in Scotland, Staffordshire, and a few other localities, and except in Scotland (and some-times even there) it is usually mixed with coke. The coal used is of the kind called splirt coal, a non-caking coal burn-ing with a long flame. It yields only from 50 to 65 per cent. of coke, and this coke is soft and friable. The volatile matter is expelled near the top of the furnace, so that it is only the fixed carbon of the coke which is available for combustion, and therefore a larger quantity of coal than of coke is required for the production of the same weight of iron. In Scotland about 32 cwts. to 36 cwts. of coal are used for each ton of iron produced. Owing to the coke yielded by splint coals being very friable, the furnaces used are always of small size, an actual working depth of 45 ft. to 50 ft. being the greatest that can be used satisfactorily, or somewhat more if a mixture of coal and coke be used.

Anthracite is a dense coal containing very little volatile matter. It is not porous, and so presents only a small surface to combustion, and tends to crumble to powder under pressure when hot. A high blast pressure is therefore required when it is used. Anthracite is now rarely used except mixed with coke.

The following table will give an idea of the composition of the various fuels :—

	A	B	C	D	E	F
Volatile Matter	—	—	—	·460	42·30	42·05
Fixed Matter—*i.e.*						
Coke	100·00	100·00	100·00	99·540	57·70	57·95
Fixed Carbon	97·00	87·57	90·31	89·576	54·90	54·00
Ash	3·00	10·15	8·45	9·113	2·80	3·95
Sulphur	—	1·73	1·25	·821	·88	1·15
Moisture	—	·55	—	·210	7·1	8·10

A.—Charcoal. B.—Yorkshire Coke. C.—Scotch Coke. D.—Connels-ville Coke. E.—Govan Splint Coal. F.—Russel Splint Coal.

As already remarked, the quantity of air required is about 6 tons for each ton of carbon consumed, so that it really forms the largest portion of the income of the furnace.

FURNACE CHARGES.

The proportions of the various materials to be charged into the furnace must be carefully determined, and this can only be done if the composition of the material being used is exactly known, and therefore the chemical laboratory is a very important part of the equipment of a modern works working under the best conditions. In the earlier works, where ore of only one quality, usually obtained from one mine, was used, analysis was of less importance, but now with materials of very varying composition drawn from all parts of the world, accurate analysis is essential.

The various cargoes of ore as they come in will be sampled and analysed, and of course kept in separate ore bins. The calculations to be made will be, in general, three :—

(1) To ascertain the amount of flux (limestone) to be added to the charge.

(2) To ascertain the amount and composition of the iron which will be obtained.

(3) To ascertain the proportions in which ores must be mixed to give an iron of definite composition.

In order that these calculations may be made, it is necessary to know :—

(1) The composition of the ore.

(2) The amount and composition of the ash of the fuel being used.

(3) The composition of the limestone available as a flux.

(4) The type of silicate which it is intended the slag shall be.

In order to illustrate the method of making the calculations the simplest plan will be to take an example. Assume that the ore to be used has the following composition :—

Ferric oxide	. .	70 per cent.	= Iron	.	49·00 per cent.
Manganese oxide	.	2	„	= Manganese	1·55 „
Alumina	. . .	4	„		
Lime .	. . .	2	„		
Magnesia	. . .	1	„		
Silica .	. . .	12	„		
Sulphur	. . .	1	„		
Phosphoric anhydride	1	„	= Phosphorus	·43 „	
Water	. . .	7	„		
		———			
		100			

The coke contains 1 per cent. of sulphur, and yields 10 per cent. of ash, which has the composition :—

Silica					50·0 per cent.
Alumina .	.	.	.	.	45·0 ,,
Lime	.	.	.	.	2·5 ,,
Magnesia.	.	.	.	.	2·5 ,,
					100·0

The available limestone contains :—

Calcium carbonate	.	.	.	97 per cent.
Silica	.	.	.	3 ,,
				100

A. The Amount and Composition of the Iron that will be Obtained.—The furnace is being run for a No. 1 iron to contain about 3·5 per cent. of carbon and 2·5 per cent. of silicon. It may be assumed that other impurities will be about 2 per cent. This can be judged roughly from the analysis of the ore, and great accuracy is not necessary, as the iron cannot be made exactly to the required composition. The pig iron will then contain 92 per cent. of iron.

The ore yields 49 per cent. of pure iron, but the amount of pig iron will be larger in the proportion of 92 : 100—that is,

$$\frac{49 \times 100}{92} = 53\cdot25,$$ say 53·2 per cent., or 1 ton will yield about

10·7 cwt. of pig iron. The whole of the phosphorus and one half of the manganese will pass into the iron. The ore contains ·43 per cent. of phosphorus. That is, there will be ·43 lb. of phosphorus in the 52·7 lb. of pig iron, so that the composition will be $\frac{43 \times 100}{53\cdot2} = \cdot808$, say ·81 per cent. The ore

contains 1·55 per cent. of manganese, of which one-half will probably go into the iron ; the percentage will therefore be $\frac{\cdot77 \times 100}{53\cdot25} = 1\cdot45$, say 1·5 per cent. The pig iron will therefore contain :—

Iron	.	.	.	.	91·7 per cent.
Carbon	.	.	.	.	3·5 ,,
Silicon	.	.	.	.	2·5 ,,
Manganese	.	.	.	.	1·5 ,,
Phosphorus	.	.	.	.	·8 ,,

<div align="center">100·0</div>

These figures are, of course, only approximate, and the iron contains only 91·7 instead of the 92 per cent. of iron assumed.

It is obvious that this method of calculation would not be applicable if there were a large quantity of phosphorus or manganese present, unless the percentage of iron likely to be present be judged, as it easily can be, from the analysis of the ore.

Suppose the ore had contained 3 per cent. of phosphorus. Taking in all other respects the same figures as before, it is seen that the iron and phosphorus together will amount to about 93 per cent. of the weight of the pig-iron, so that the amount of iron obtained for each 100 lbs. of ore will be

$$\frac{(49 + 3)}{93} \times 100 = 55·9,$$ say 56 lbs. In this 56 lbs. there will

be 3 lbs. of phosphorus, so that the percentage will be

$$\frac{3 \times 100}{56} = 5·36,$$ say 5·4%. · As the total amount of pig-iron

produced per ton of ore is slightly larger, the percentage of manganese will be slightly less by

$$\frac{·77 \times 100}{56} = 1·19,$$ say 1·2%,

and the composition of the iron will be :—

Iron	.	.	.	.	87·5 per cent.
Carbon	.	.	.	.	3·5 ,,
Silicon	.	.	.	.	2·5 ,,
Manganese	.	.	.	.	1·1 ,,
Phosphorus	.	.	.	.	5·4 ,,

<div align="center">100·0</div>

Calculation of the Charge.—In running for a No. 1 iron from a hæmatite ore it may be assumed that each ton of iron produced will require 22 cwts. of coke, or 100 lbs. of iron will

require 110 lbs. of coke, so that 53·2 lbs. of iron or 100 lbs. of ore will require 58·5 lbs.; so that the charge will consist of 100 lbs. of ore to 58·5 lbs. of coke.

The most important calculation is that for the quantity of limestone which has to be added for fluxing. In order to ascertain this, the type of slag to be produced must be determined on. This may be stated in several ways, and the calculation will be slightly different, according to the basis adopted. It may be decided to make a slag containing a definite percentage of silica or one of a definite type. In the former case the type will vary with the nature of the bases, since different bases combine with different proportions of silica, and in the latter case the percentage of silica will vary with the bases present. In all respects the type system is the best, though the silica percentage is the most generally used.

Assume the slag to be of the mono-silicate type—that is, such as $2CaOSiO_2$, containing two molecules of lime to one of silica, which, if no base but lime were present, would contain 34·9 per cent. of silica and 65·1 per cent. of lime.

It is quite obvious that if two silicates of the same type be taken, but containing different bases, as, for instance, $2CaOSiO_2$ and $2MgOSiO_2$, the proportions of silica to base will be different, and that it will be easy in the case of any given base to calculate a factor which by simple multiplication will give the amount of silica that will be required to combine with any base to form a silicate of the type required. These factors are used in what follows, and the method of calculating them is fully explained in the appendix.

The bases to be fluxed away are manganese oxide (one-half of that present), lime, magnesia, and alumina, which in these calculations is regarded as being a base :—

Base.	Percentage.	Factor.*	Amount of Silica Required.
Manganese oxide	1 ×	·423	·423
Alumina . .	4 ×	·882	3·528
Lime . .	2 ×	·536	1·072
Magnesia . .	1 ×	·750	·750
Total	. .	. . ;	5·773

* For table of factors see p. 248.

That is, the bases in 100 lbs. of ore will flux 5·773 lbs. of silica, leaving $12 - 5.773 = 6.227$ to be fluxed by added lime. The percentage composition of the coke ash has been given, but as each 100 lbs. of ore requires 58·5 lbs. of coke, and the coke contains 10 per cent. of ash, there will only be 5·8 lbs. of ash per 100 lbs. of ore. Or :—

$$\text{Silica} \quad \frac{50 \ \times \ 5.8}{100} = 2.90 \text{ lbs.}$$

$$\text{Alumina} \quad \frac{45 \ \times \ 5.8}{100} = 2.61 \ \text{,,}$$

$$\text{Lime} \quad \frac{2.5 \ \times \ 5.8}{100} = .146 \ \text{,,}$$

$$\text{Magnesia} \quad \frac{2.5 \ \times \ 5.8}{100} = .146 \ \text{,,}$$

The bases can now be multiplied by the factors as before :—

Alumina	.	.	.	2·61	×	·882 =	2·30
Lime	.	.	.	·146	×	·536 =	·08
Magnesia	.	.	.	·146	×	·750 =	·11

$$\overline{\quad 2.49 \text{ lbs.}}$$

so that the bases present will combine with 2·49 of the 2·90 lbs. of silica present, leaving $2.90 - 2.49 = .41$ lb. to be fluxed by the added lime.

The total silica to be fluxed away is therefore $6.23 + .41 = 6.64$ lbs., less the silica which goes into the pig-iron as silicon : viz. $(.025 \times 53.2) \times 60 \div 28 = 2.22$ lbs.

The limestone contains :—

Lime	.	.	.	54·3	per cent.
Carbon dioxide	.	.	.	42·7	,,
Silica	.	.	.	.	3·0	,,

$$\overline{\quad 100.0 \quad}$$

The carbon dioxide will, of course, be expelled. The silica present will combine with $3 \times 1.86 = 5.58$ parts of lime to form a mono-silicate, so that the available lime is $54.3 - 5.58 = 48.72$ lbs. for each 100 lbs. of limestone.

The amount of silica to be fluxed away is 4·42 lbs., and this will require $4.42 \times 1.86 = 8.74$ lbs. of lime, or $\dfrac{8.74 \ \times \ 100}{48.72} = 16.88$ lbs. of limestone.

There is still one item to be taken into account. Both the ore and the coke contain sulphur, and lime must be provided to carry this into the slag as calcium sulphide (CaS).

The amount of sulphur is :—

In 100 lbs. of ore . . . 1·000 lb.
In 4·58 lbs. of coke . . . ·058 „
                                        ─────
                                        1·058 „

This will require 1·058 × 1·75 = 1·85 lbs. of lime, or $\dfrac{1·85 × 100}{48·72}$ = 3·97, say 4 lbs. of limestone. The charge will therefore be :—

Ore . . . 100·0 lbs. or   20 cwts.
Coke . . . 58·5 „ = 11·7, say 12 „
Limestone . . 20·8 „ = 5·0, „   5 „

a little additional lime being usually added to keep the slag basic.

Calculations can be made in a similar way if a slag with a given percentage of silica is aimed at.

The composition of the slag can be calculated by collecting together the weights of the various constituents from the three sources.

Ore Mixing.—It is often necessary to ascertain the proportions in which ores should be mixed so as to obtain iron of a given composition. The proportions are often judged by inspection of the analyses, the mixture thus made being considered as a single ore, and the calculations made exactly as described.

Only one case will be considered. Two ores are in stock— an ore A, which contains 60 per cent. of iron and ·08 per cent. of phosphorus ; and an ore B, which contains 45 per cent. of iron and 1·6 per cent. phosphorus—and it is required to make an iron containing 1·0 per cent. phosphorus. It is quite obvious that if A alone were used the iron would be low in phosphorus, and if B alone were used it would be too high.

It may be assumed that the pig-iron will contain about 92 per cent. of iron, and this must therefore be the basis of the calculation. In A : for each 92 parts of iron there is $\dfrac{92 × ·08}{60}$ = ·12 parts of phosphorus. In B : for each

92 parts of iron there is $\dfrac{92 \times 1\cdot 6}{45} = 3\cdot27$ parts of phosphorus. Taking A as the basis, we have for each 92 parts of iron :—

	P Present.	P Required.	Deficiency.	Excess.
A	·12	1	·88	—
B	3·27	1	—	2·27

so that the ores must be mixed so as to yield iron in the proportion $\dfrac{2\cdot27}{\cdot88} = 2\cdot58$. That is, for each 1 part of iron yielded by B, 2·58 parts must be yielded by A, thus :—

	P Present.	P Required.	Deficiency.	Excess.
A	·12 × 2·58 = ·309	2·58	2·271	—
B	3·27	1·00	—	2·271

To yield 100 parts of iron 222 parts of B would be required, and to yield 258 parts of iron 430 parts of A would be required, so that the ores would be mixed in the proportions of 222 to 430 or 100 B to 194 A, or probably, in round numbers, 20 cwts. B to 39 cwts. A would give the composition required. Similar calculations can be made for any other element, and of course more than two ores may be mixed.

Economy of a Furnace.—The economy with which a furnace is working is measured by the amount of fuel consumed for each ton of iron produced, and this will depend on the ratio between the heat utilised and the heat lost.

It has been found that increase in the size of the furnace has led to increased economy ; that is, to a reduction in the amount of fuel used.

Increase in height tends to economy because the gases are more perfectly cooled, and therefore carry away less heat, and also because the ore is longer in the zone of reduction, and therefore is more perfectly reduced by the carbon mon-oxide ; but a point is reached, varying with the conditions of working, when increased height no longer produces economy, the gases not being further cooled. This is partly, at least, due to the fact that the reaction by which the iron oxide is decomposed evolves heat, and as this takes place near the top of the furnace, it prevents complete cooling of the gases. In British working, with hard coke as fuel, the height of the most economical furnace is about 90 ft. In Scotland, where coal is used, the furnaces are rarely over 60 ft. in height.

Increase in the diameter of a furnace has a similar result, as the wider the furnace the more slowly the gas current passes upward. A limit is put to the diameter of the hearth by the blowing power available, and the furnace must not be so wide in any part that there is not a regular upward flow of the gas through the materials in all parts. That therefore fixes a limit to the diameter of the furnace.

These conditions are to be taken as being generally true, since much depends on the conditions under which the furnace is being worked. In general, the consumption of fuel may be taken as being :—

British coke-fed furnaces working on Cleveland ores,
    21 cwts. to 22 cwts. per ton of iron.
American coke-fed furnaces working on hæmatite ores,
    18 cwts. to 20 cwts. per ton of iron.
Scotch coal-fed furnaces working on hæmatite ores,
    30 cwts. to 36 cwts. of splint coal per ton of iron.

Output of Furnaces.—The output which can be obtained from a furnace varies with the conditions. Obviously, the larger the output that can be obtained the better, provided that there is no decrease in economy and the furnace is not too rapidly worn out.

At the two extremes may be put Scotch practice with raw coal, the average output being about 300 tons per week, and American practice, as it is called, though carried out at many British works, with an output up to 2,000 tons per week ; whilst the old Cleveland practice, with coke as fuel and an output of 800 tons or so per week, stands in between.

The output or, what comes to the same thing, the rate of driving depends mainly on the amount of air supplied to the furnace. There is always plenty of fuel in the furnace. The more rapidly this burns away, the more rapidly the charge will descend, the larger will be the amount of iron obtained. Hence in new furnaces intended for rapid driving the number of tuyeres is increased to eight or ten, and these are made of large diameter. It must be remembered that the area increases as the square of the diameter, so that a 7-in. tuyere will pass four times as much air as a 3½-in. tuyere—indeed, rather more, owing to lessened friction—at the same pressure. The blast is also supplied at a higher pressure so as to get a more rapid air current.

It has already been pointed out that for very rapid work-
ing, mechanical devices must be used for charging and re-
moving the metal; also that, owing to the rapid combustion,
the temperature becomes very high and the bosh of the fur-
nace must be continually cooled. Whether rapid driving will
be advantageous or not will depend on circumstances. In
Scotch furnaces, where the fuel is coal from which the volatile
matter has to be expelled and the ores used are hard and
dense, rapid driving has not been found to be possible. On
the other hand, in America, with soft, porous hæmatites, it
has been found to be quite satisfactory. For every condition
of fuel and ore there will be a maximum rate of descent of the
charge, beyond which any increase will cease to be economical.

With rapid working the character of the iron is usually
modified. It comes down so rapidly that it is not left long in
contact with the other materials of the charge; therefore
less silicon is reduced, so that American irons, or those made
in this country in furnaces driven very rapidly, are usually low
in silicon, often not containing more than 1 to 1·5 per cent.
The more rapid the driving the more quickly will the furnace-
lining wear out. Scotch furnaces often remain in blast twenty
years or more, whilst the furnaces that are driven hard re-
quire re-lining every two or three years. The whole question
of rate of driving is more a question of economy than of
scientific principle, and ironmasters soon find out what is the
most economical rate of driving under the conditions of their
works.

The Hot Blast.—The introduction of the hot blast by
Neilson in 1828 led to a great saving in fuel. The effect pro-
duced at the Clyde iron works where the hot blast was intro-
duced will be seen from the following figures :—

	Weekly Make per Furnace.		Coal Used per Ton.		
	tons	cwt.	tons	cwt.	lb.
1829, January to August, Coke and Cold Air	36	18	8	19	1
1830, January to August, Coke and Air at 300°	54	1	5	3	1
1833, January to August, Coke and Air at 600°	61	1	2	5	1

To-day, with the blast at 1,400° F. and raw coal as fuel, the weekly make is about 300 tons, and the consumption of fuel about 32 cwts. The changes shown from 1829 to 1833 were entirely due to the use of the hot blast, since no other changes were made in the working, and in each case the coal consumption includes that used in heating the air, since it was not till later that attempts were made to utilise the waste gas for heating purposes. It may also be noted that the coal was coked—raw coal not being used till after 1831 ; and the wasteful method of coking led to considerable waste of fuel ; but this would be the same in each of the three years. The furnaces also were very small. For these reasons, whilst the introduction of the hot blast always led to saving of fuel, in no other district was the saving so large as in Scotland.

The tendency of late has been to use the blast as hot as possible, 1,400° to 1,450° F. being the usual temperature ; and each increase in the temperature of the blast has led to increased saving in fuel, but in a constantly diminishing ratio.

The reasons for the saving, leaving out of account the fact that the heat is now obtained from the waste gases, and therefore that some of the heat is carried back into the furnace, seem to be :—

(1) That the quantity of gas passing through the furnace is considerably diminished, and therefore that it can be more effectively cooled.

(2) One essential for good working is that the actual zone of fusion opposite the tuyeres should be very hot, and there is no advantage in extending this zone upwards. When air is blown into the furnace, by the combustion which takes place it becomes intensely heated, and therefore expands, and this expansion absorbs heat and this tends to cool the furnace. It is obvious that the greater the rise of temperature the greater will be the absorption of heat and consequent cooling, and therefore the fusion zone will be higher.

To send in the same weight of air the volume is much greater for hot than for cold air, and therefore all pipes must be made larger as the temperature of the blast is increased. The early ironmasters noticed that the output was larger in winter than in summer, this being due to the air being cooler, and therefore denser, so that more was sent in, and also to

it being drier ; and some of them had the idea, therefore, that it would be better to cool the air rather than heat it.

Kind of Iron Produced.—The variety of iron produced in the furnace is not absolutely under control, as the furnace will sometimes run an iron not desired, but, in general, iron of required quality can be made. The output as to quality and quantity can be controlled by varying the proportions of ore flux and fuel in the charge and by varying the temperature and quantity of the blast.

When the proportion of fuel to the ore is small, the furnace is said to have a heavy burden. When it is large it has a light burden. For the production of irons high in silicon, such as No. 1, the furnace must be worked at a high temperature, and therefore the proportion of fuel must be large or the burden light. The charge must also descend at such a rate as to allow of the silicon being taken up. With very rapid driving, as already remarked, the iron tends to be low in silicon. The quantity of lime must be only sufficient to form a good slag ; if the quantity is insufficient, a siliceous slag may be formed, and too much silicon may pass into the iron. The obvious remedy is to increase the amount of limestone in the charge.

When it is required to make an iron very high in silicon, the quantity of fuel is largely increased and the quantity of lime is reduced. By these means a very high temperature is obtained, and very refractory siliceous slag, which usually contains some iron, is produced.

Manganese is difficult to reduce, and the oxide combines readily with silica. When it is required to pass manganese into the iron—the manganese, of course, being in the ore— a large quantity of fuel must be used, so as to produce a high temperature and at the same time a considerable quantity of lime must be added to keep the slag basic.

When the furnace is worked with a heavy burden, the temperature is low, but little silicon is reduced, and the iron tends to be white and at the same time to take up sulphur. The more basic the slag the less sulphur will be taken up by the iron.

By carefully adjusting the conditions, the skilful blast manager can usually produce iron of any quality which he requires, and the demands of the trade to-day require the

K

production of iron of very varying quality for different purposes.

The fusibility of the slag may have considerable influence on the quality of the iron, and should be adjusted to the temperature of the furnace. A very fusible slag will melt high up the furnace and run down into the hearth, whilst a less fusible one will remain mingled with the charge until it is much further down. Once a slag melts and runs down it is out of the sphere of action. When iron passes into the slag it is probably not from unreduced iron oxide, since reduction should be complete at a temperature below that at which the combination of the oxide of iron and silica can take place, but is probably mainly produced from iron oxidised by the carbon monoxide; and this action, according to Sir Lowthan Bell, becomes less energetic as the temperature rises. When a furnace is working at a low temperature, and with the production of a very fusible slag, iron may be readily taken up, and may not be reduced on running through the charge. On the other hand, if the slag is not so fusible, it will reach a temperature at which oxide of iron is not formed or cannot exist before it melts. Whilst the slag is in a partly unfused condition it can still be acted on by the agents around. Highly siliceous slags are difficultly fusible, and therefore retain the silica in a condition in which it can be reduced by the carbon.

Accidents.—Scaffolds and slips have already been mentioned. Explosions sometimes occur, at the hearth from the bursting of a water tuyere, and at the top of the furnace from causes of which at present little is known. It is not likely to be leakage of air, since there is always a pressure in the furnace, though the slip of a scaffold might cause a partial vacuum, and this perhaps might draw in air enough to cause an explosion. Wet ore, if suddenly let down by a slip into a hot part of the furnace, might suddenly evolve enough steam to produce an explosion. Explosions at the furnace top are not common, but are sometimes disastrous.

CHAPTER XII.

THE BY-PRODUCTS.

As the blast furnace is worked for the production of iron, anything else that may be obtained, whether of value or not, must be a by-product. For each ton of iron produced there will be, under ordinary circumstances :—

Slag from ·5 to 2 tons.

Gases about 8 tons.

These gases, in the case of coal-fed furnaces, carrying a considerable quantity of tar and ammonia.

It becomes, therefore, a matter of very considerable importance to utilise, if it be possible, this large quantity of material.

Slag.—The amount of slag produced in Middlesborough and in Scotland is about 1·5 tons for each ton of iron made. In the hæmatite districts, where the ores are much richer, the amount is about one ton, or sometimes less.

The disposal of the slag is very troublesome and costly, and many attempts have been made to utilise it in various ways.

Ballast.—The slag may be broken up and used as ballast for railways or for road making. A considerable quantity of slag is used for this purpose. It must not be too high in lime or would crumble to pieces under the influence of air and moisture.

Cement.—A very good cement can be made from a suitable slag, one which contains a fair proportion of alumina and not more than about 3 per cent. of magnesia. The hydraulic power of cement seems to be due to the presence of basic silicates and aluminates of lime which dissolve momentarily in water, then absorb water and crystallise. The calcium silicate having the greatest setting power is said to have the formula $3CaO,SiO_2$. If the constituents be fused in this proportion a fusible slag is produced, but as it solidifies it breaks up, probably forming $2CaO,SiO_2$ and free lime ;

therefore slags rich in lime disintegrate on exposure to the air owing to the slaking of the lime. The basic silicate can be formed, however, by heating the constituents to a temperature somewhat below the fusing point of this silicate.

The slag is granulated by being run into water, dried, and crushed to an impalpable powder. The requisite amount of lime is crushed and the two constituents are thoroughly mixed. The mixture is then calcined in a suitable kiln till particles adhere, forming " clinker," the size of the lumps of " clinker " varying with the form of the kiln in which the operation takes place. The " clinker " is ground, and the ground material is a cement in all respects resembling Portland cement. It may be used alone, or very often is mixed with Portland cement.

Bricks.—At one time building bricks were made by mixing pulverised slag with cement, pressing under hydraulic pressure, and allowing it to harden in the air. From some varieties of slag, bricks suitable for paving or building may be made by casting the slag in suitable moulds.

Paving Blocks.—These are now made on a large scale. The slag is crushed, mixed with a quantity of Portland cement, and the slabs are compressed under hydraulic pressure of about 500 lb. per square inch. Such blocks are very durable.

Slag wool (silicate cotton) is largely used as a non-conducting material. A cubic foot of slag yields about 12 cub. ft. of wool, and the entangled air makes it a good non-conductor. The wool is made by blowing a stream of air or steam across a stream of molten slag, and subsequently separating the globules of fused slag.

All these uses, however, account for but a small proportion of the slag actually produced. The bulk of it still accumulates in slag heaps.

Gas.—The gas, as already remarked, forms the largest proportion of the by-products, and from the large quantity of carbon-monoxide it contains it is always valuable as a fuel.

The gas is now used for heating the blast, the raising of steam, the direct driving of gas engines, and for other purposes. About 25 per cent. by volume of the gas is composed of combustible carbon-monoxide, and the heating power of the escaping gases per ton of metal produced in the Cleveland furnace is equal to that furnished by the

combustion of about 11½ cwts. of coal. Blast furnace gas contains as carbon-dioxide and as carbon-monoxide, the whole of the carbon of the fuel and of limestone introduced into the furnace except that absorbed in the recarburisation of the reduced iron to the state of pig-iron, and the small amount escaping as cyanogen, in combination with potassium or sodium, as cyanide.

ANALYSES OF BLAST FURNACE GAS BY VOLUME.

	A	B	C	D	E
Nitrogen	55·35	57·22	57·06	62·34	57·79
Carbon-monoxide	25·97	24·65	28·61	24·20	23·51
Carbon-dioxide	7·77	12·01	11·39	8·77	12·88
Marsh gas (CH_4)..	3·75	0·93	0·20	3·36	—
Olefiant gas (C_2H_4)	0·43	—	—	—	—
Hydrogen	6·73	5·19	2·74	1·33	5·82
	100·00	100·00	100·00	100·00	100·00

A.—Alfreton furnace working upon calcined argillaceous ironstone and raw coal, blast heated to 626° F. (320° C.) (Bunsen and Playfair). B.—French furnace working upon brown hæmatite, lime and charcoal (Ebelmen). C.—Seraing upon brown hæmatite, mill, cinder, lime and coke blast 212° F. (100° C.) (Ebelmen). D.—Charcoal furnace (Bunsen). E.—French furnace working upon hæmatite, lime flux and charcoal (Ebelmen).

The gases do not differ essentially in composition whether hot or cold blast is employed, or whether charcoal or coke is the fuel employed.

Nitrogen forms more than 50 per cent. and carbon-monoxide (CO) 25 per cent. or more of the total volume; and the higher the ratio of carbon-dioxide to carbon-monoxide, the greater is the economy in the consumption of fuel, though this ratio can never be greater than 1 : 2 under ordinary conditions; also the lower the temperature at which the gases escape from the furnace, the less is the heat carried away and lost. The ratio of oxygen to nitrogen in the gases is in excess of that in the atmosphere, as a considerable quantity is derived from the reduction of the oxides of iron in the iron ores, and is contained in the carbon-dioxide expelled from the limestone added as a flux; while the free hydrogen is derived from the decomposition of water vapour carried in by the blast.

When raw coal is used, the gases are necessarily richer in hydrogen and in hydrocarbons, since the coal gas, which consists mainly of these gases, mixes with the gases produced by the combustion of the coke, in this case also the gases carry over a quantity of tar and ammonia ; but as these are condensed before the sample is analysed, the green (or unwashed) and the washed gases do not show any difference in composition.

The following analyses of gases from Scotch coal-fed furnaces will indicate their general character :—

	A	B	C
Nitrogen	59·27	56·50	55·86
Carbon-monoxide	27·51	27·40	27·20
Carbon-dioxide	6·15	6·60	6·60
Marsh Gas	3·02	2·64	2·68
Hydrogen	3·68	6·86	7·66
	99·63	100·00	100·00

A and B.—Unwashed.   C.—Washed.

It is quite obvious that, considered as a source of heat, the gas from a coal-fed furnace is better than that from one that is coke-fed.

The current of waste-gas also carries over with it into the tubes and flues an amount of dust, containing silica, alumina, ferric oxide, lime, calcium sulphate and phosphate, with smaller proportions also of magnesia, manganese oxide, potash, soda ; and if the ores contain zinc, then this dust will contain in addition zinc oxide. This dust accumulates slowly in the flues, and requires to be cleared away from time to time ; or it is separated by washing arrangements connected with the top of the furnace.

In the case of a coal-fed furnace the tar would also accumulate. The dust in the one case and the tar in the other render the gas unsuitable for use in gas engines without some purification. In the case of coke-fed furnaces, all that is needed is a simple washing, but with coal-fed furnaces more elaborate processes are resorted to so as to recover the tar and ammonia, which are of considerable value.

Washing the Gas from the Coke-fed Furnaces.—The gas is passed through vessels in which water is kept in a violent state of agitation by means of dashers, so that the dust is washed out of the gas, and if necessary it is then passed through some filtering material to remove the last traces.

Recovery of Tar and Ammonia.—Ordinary Scotch splint coal contains about 1·4 per cent. of nitrogen, and when the coal is distilled in the blast furnace about 16 per cent. of this comes off in the form of ammonia. This is equal to about ·22 per cent. of nitrogen, given off as ammonia, or 4 to 5 lbs. of nitrogen, or 23·5 lbs. of ammonium sulphate per ton of coal consumed. This is, of course, a small amount, but when the
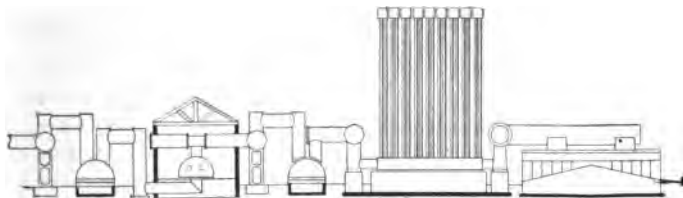
Fig. 63.—Gillespie By-product Plant, Section.

enormous amount of coal consumed is taken into account, it becomes of value.

', The first plant erected to recover the tar and ammonia was that of Messrs. Alexander and M'Cosh at the Gartsherrie iron works, and the principle which they adopted of cooling the gas and then scrubbing or washing with water has been followed in all other plants since erected.

Three types of plant are in use. The one to be described is that of Messrs. Gillespie (Fig. 63), which has been erected at many works in Scotland, and in which the costly scrubbers used in the older systems are dispensed with.

The amount of gas to be dealt with is enormous. Each ton of coal will give about 120,000 cub. ft. of gas through which the small quantities of condensible products are distributed, and in order to separate these the gas must be thoroughly cooled and then treated with water. The Scotch furnaces are small, consuming about 75 tons of coal in twenty-four hours, so that there will be about 8,600,000 cub. ft.

of gas per day per furnace, or for a works with eight furnaces about 71,000,000 cub. ft. of gas per day. It is this enormous amount of gas that makes the problem of recovery so difficult.

The gas will leave the furnace at a temperature of about 300° C., or a little less, and will cool somewhat on its way to the condensing plant. It passes through a dust-catcher attached to the furnace, where some of the coarser dust settles, then by large mains to the condensing plant.

The gas is passed through a tar washer—a large iron vessel containing tar; this keeps back the dust, which would otherwise be carried over, and at the same time acts as a seal, so as to cut off the gas in the mains from that in the recovery plant. Then the gas passes to the atmospheric condenser. This consists of a series of about 200 vertical iron tubes 60 or 70 ft. in height and 2 ft. 6 in. or so in diameter. They are arranged in series on iron boxes so that the gas has to traverse about twenty tubes up and down, and so that any series of twenty can be cut out if necessary. In this condenser the temperature is reduced to about 60° C., but only a little tar separates; probably it is in such a fine state of division that it is carried forward mechanically. Then the gas is passed through the first washer. The washers are all alike, and consist of long iron boxes divided by screens, so arranged that owing to the large area the gas travels very slowly, and by passing under the screens it is broken up into innumerable, very minute bubbles which pass upward through the water.

The resistance to the passage of the gas is so great that the pressure in the blast furnace would not be sufficient to force it through the apparatus, so that it becomes necessary to use a blower of some kind. In the first forms of plant a Roots blower was used to draw the gas through the first washer and force it onward through the second, or in some cases second and third; but in the latest installations these are replaced by exhausters driven by Parsons turbines. If three washers are used fresh water is supplied to the third. This is then pumped into the second, and then into the first, so that the gas passes through clean water in the last washer. The water containing the tar and ammonia is run into large settling tanks, where the tar sinks to the

bottom, and thence the two can be drawn off separately for further treatment.

The products are :—

(1) **The Gas.**—This is now nearly free from tar and ammonia, and is passed on to the boilers and stoves. It still contains a minute trace of tar, and for use in gas engines needs some further treatment. It burns with a non-luminous flame, and of course its heating power is less than that of the green gas before washing, but still will be greater than that of gas from a coke-fed furnace. The gas is clean to use, and having been well cooled contains but little water.

(2) **The Tar.**—About 40 gallons (say 400 lbs.) of green tar is obtained for each ton of coal consumed. This is forced up into large stills, very like the common haystack boiler, and is heated till all the water is expelled, when about 5 lbs. of anhydrous tar will be left from each gallon of " green " tar. The boiled tar is then quickly heated, and breaks up into oils which pass over, and a residue of pitch which remains. The oil may be collected in one tank, but is usually fractioned, the receiver being changed during the process. Two fractions are thus obtained :—

(1) Lucigen oil, having a specific gravity of about ·970.

(2) Creosote oil, having a specific gravity of about ·989.

The Lucigen oil is largely used for burning in lucigen and other blast lamps, as a fuel, and for other purposes. The creosote oil contains phenols, and may be used as a disinfectant. One firm prepares from it a disinfectant which is sold under the name of neosote, and which is said to be equal in power to carbolic acid. The unfractioned oil is used as fuel for steam boilers and other purposes. The amount of oil obtainable varies, but may be taken as being roughly 40 per cent. of the tar, or say 6 to 6½ gallons per ton of coal consumed. The amount of oil varies also with the variety of pitch required : the softer the pitch the less oil will be distilled out, and in any case the distillation must be stopped when the pitch is liquid enough to flow from the still.

The demand for the pitch is considerable. It is used in the manufacture of fuel briquettes, for setting in road paving, and for many other purposes.

The tar is very different from that which is obtained in a gas works. It must be remembered that the tar

does not exist as such in the coal, but is produced by the process of destructive distillation, and consequently the nature of the product will depend on the conditions under which it is produced. The tar from the blast furnace contains little or no benzene, which is the source of aniline, and thence of the coal-tar colours ; and it is, therefore, of much less value than coal tar. The reason for the difference is that in the blast furnace the distillation takes place at a very low temperature, for it is brought about at the top of the charge by the hot gases, the temperature of which, as already mentioned, is about 400° C.

(3) **Ammonia.**—The ammonia liquor contains the ammonia almost entirely in the free condition. It is pumped to the top of a series of stills, down which it falls, meeting an ascending current of steam. The ammonia is carried forward with the steam, passed into sulphuric acid, and crystallised ; the crystals are fished or blown out of the saturator, dried in a centrifugal drier ; and are then ready for the market. The yield varies according to the amount of nitrogen in the coal from 20 to 25 lbs. of sulphate per ton of coal. The amount may, no doubt, also vary with the way in which the nitrogen is combined in the coal so that it is impossible to say from an analysis of the coal exactly how much ammonia should be obtained. The 16 per cent. already mentioned is, however, a fair average. We may now, perhaps, sum up the value of the products obtainable. Taking as a basis the production of 1 ton of pig iron, the output will be about :—

Pig iron, value, one ton, say . .	£2	5	0
Ammonium sulphate, 24 lbs. . .	0	3	4
Pitch, 160 lbs.	0	1	8½
Oils, 15 gallons	0	1	10½
	£2	11	11

The value of the by-products is thus shown to be 6s. 11d. per ton of iron, or nearly one-sixth of the value of the iron itself.

The following figures have been published with reference

to an installation of the Gillespie plant for four furnaces making hæmatite pig-iron :—

Coal consumed.	.	2,000 tons per week.	
Pig-iron produced	.	1,400 ,, ,, ,,	
Pitch recovered	.	100 tons,	value £120
Oil recovered .	. 20,000 gallons,	,,	125
Sulphate of ammonia	20½ tons,	,,	225

<div align="center">

Total by-products . . . £470

</div>

The wages and other costs of working the plant are put at £30, and the cost of acid at £20 10s., leaving a handsome balance for interest, depreciation, and profit. Recovery plant has been put up in two or three English works, but as at all these the fuel used is a mixture of coal and coke, the yield is considerably less than in Scotland. Every iron works in Scotland, with one exception, is now fitted with recovery plant. The cost of the plant is high, reaching £5,000 or £6,000 per furnace.

Accidental Products.—Various minor by-products are sometimes obtained. If the ores contain lead, this may be tapped out with the iron. If zinc is present, it will collect in the flue dust. As already mentioned, cyanides are always formed, but up to the present no method has been found for the profitable recovery of them.

CHAPTER XIII.

MALLEABLE- OR WROUGHT-IRON.

MALLEABLE-, wrought-, or bar-iron, under which names the same metallurgical product is known, was formerly described as iron in its lowest degree of carburisation; but now all attempts to frame a definition of malleable iron upon a chemical basis have been futile, since in its low percentage of carbon, comparative freedom from such impurities as silicon, sulphur, phosphorus, etc., occurring so largely in pig-iron, it is rivalled or even excelled by the Siemens and the Bessemer mild steels; but malleable-iron differs from these materials even when otherwise of the same chemical composition, in the fact that it always contains particles of intermixed slag and oxide. A definition based on mode of production could be framed, because the metal has not been fused, but formed by the welding together of pasty messes under pressure.

Bar-, wrought-, or malleable-iron has a dull-bluish or blackish-grey colour, varying somewhat with its previous mechanical treatment, as to hammering, rolling, etc. Its fracture after hammering or rolling is of a fibrous character in the softer varieties, but becomes granular or crystalline in the harder kinds. The higher qualities of bar-iron present when broken a certain silky, fibrous appearance, which under repeated and long-continued vibration again assumes a granular or crystalline structure. The fractured surfaces are, however, more or less deceptive, since specimens broken by progressively increasing stresses are invariably fibrous, whilst the same specimen if broken by a sudden blow will exhibit a crystalline fracture.

Wrought-iron is one of the most malleable, tenacious, and ductile of the metals, its malleability increasing with the temperature short of fusion, to which it is heated. Sheets have been exhibited at Paris $\frac{1}{770}$th of an inch in thickness, and at Pittsburg, according to report, they have been produced $\frac{1}{15500}$th of an inch in thickness. Malleable-iron is

soft, but is exceeded in this respect by pure iron, and it is not sensibly altered as regards softness by being heated to redness and suddenly cooled by plunging into water ; but bars of iron are shortened by this treatment.

The melting point of wrought-iron is between 2,732° F. and 2,912° F. (1,500° C. and 1,600° C.) according to Pouillet ; it is at 3,812° F. (2,100° C.) according to Scheerer. The melting point of pure iron is now usually taken as being 1,600° C., that of commercial iron varies with the degree of carburisation and its freedom from sulphur, silicon, phosphorus, manganese, for all these impurities tend to lower its fusing point. When heated to whiteness, but before fusion occurs, it passes through a soft, pasty condition, in which two clean surfaces can be welded together, while at a red heat it is possible to hammer or forge the metal into almost any form.

Malleable-iron contains carbon from mere traces up to 0·25 per cent., occasionally reaching 0·3 per cent. ; the latter figures indicate a material decidedly steely in character. The specific gravity of malleable-iron varies between 7·3 and 7·9, average specimens being about 7·6 or 7·7 ; its linear expansion by heat is about ·000111 to ·000126 of its length for each increase of one degree Centigrade, in which respect it thus stands lower than most of the metals, as is also the case with its cubical expansion or increase of volume by heat. Its specific heat is given as ·114 at 0° C.

ANALYSES OF BAR-, WROUGHT-, OR MALLEABLE-IRON.

	A	B	C	D	E
Carbon	trace	0·075	0·016	0·180	0·230
Silicon	0·170	0·114	0·122	0·019	0·014
Sulphur	0·028	0·032	0·104	0·014	0·190
Phosphorus	0·200	0·004	0·106	0·074	0·020
Manganese	0·140	trace	0·280	trace	0·110
Iron	99·115	99·733	99·372	99·704	—
	99·653	99·958	100·000	99·991	—

A.—K.B.W. Best bar-iron (Pattinson).   B.—Swedish O O (Author).
C.—Low Moor Armour plate (Tookey).   D.—Round bar, W. R. 3
(Downar).   E.—Armour plate (Percy).

Malleable-iron may be exposed indefinitely, at the ordinary temperatures, to the action of dry air or even oxygen, without

suffering oxidation ; but in the presence also of the vapour of water, and especially, too, of carbonic anhydride, the metal is rapidly tarnished or rusted (see p. 40), the corrosion gradually extending throughout the mass, if time be given. When, however, the metal is heated to redness and exposed to the air, oxidation proceeds very rapidly with the production of a black oxide of iron or forge-scale, which scales off from the bar when it is struck by the hammer. Heated to whiteness, malleable-iron burns, throwing off scintillations from its surface, whilst the iron so heated in contact with the air becomes unweldable and friable, constituting what is known as burnt iron, a condition due to the presence of oxides of iron throughout the mass. Continued hammering of malleable-iron in the cold state induces a hard, brittle, and more or less crystalline condition in the metal.

Malleable-iron combines readily with carbon when heated in contact with charcoal, coal, carbonaceous matters, or cyanogen compounds to a temperature above redness, as is shown in the case of the manufacture of cement or blister steel, and also by the operation of case-hardening, where articles of malleable-iron are heated in contact with leather cuttings, or cyanogen compounds (potassic ferro-cyanide). Solid and gaseous cyanides, and nearly all vapours and gases containing carbon, such as carbon-monoxide and the various hydrocarbon vapours, impart carbon to iron when the latter is exposed at a red-heat for a considerable time to their action ; the carburisation proceeding from the surface towards the centre of the bar.

Red-shortness or unforgeability of malleable-iron at a red-heat usually is caused by the presence of sulphur, as small a quantity as 0·03 per cent. making the metal distinctly brittle ; copper is said to have the same effect. Cold-shortness or brittleness at ordinary temperatures is induced by the presence of small proportions of phosphorus, antimony, tin, or arsenic ; a cold-short metal may be quite malleable and ductile at or above a red-heat. Karsten observes that the presence up to 0·3 per cent. of phosphorus produces an increased hardness without affecting the tenacity of the iron, while with 0·5 per cent. of phosphorus there is a decrease in tenacity, and it becomes also cold-short, or incapable of being worked

in the cold state without cracking at the edges, although when hot such a metal can be either rolled or hammered out readily. With 0·75 per cent. of phosphorus the cold-shortness is very decided, as is also the loss of tenacity, while when the proportion of phosphorus attains to 1 per cent. the iron becomes exceedingly cold-short. Eggertz, however, states that 0·25 per cent. of phosphorus in malleable-iron renders it sensibly cold-short. Doubtless the influence of small quantities of phosphorus upon the working qualities of wrought-iron is affected by the amount of such other elements as silicon and carbon present. The late Mr. A. L. Holley, C.E., was of opinion that 0·2 per cent. of phosphorus is not injurious, but, on the contrary, improves the malleable-iron if it be accompanied by 0·15 per cent. of silicon and 0·03 per cent. of carbon.

Silicon induces hardness and brittleness in wrought-iron, 0·35 per cent. sufficing to render the iron cold-short and low in tensile strength, but it is rarely present in appreciable quantity, except in the form of silica as a constituent of the cinder mechanically distributed throughout wrought-iron.

Tin also hardens malleable-iron, but produces brittle, unweldable, and cold-short metal.

The tensile strength of malleable-iron ranges between 17 tons and 26 tons per square inch of section, the average being taken at from 22 tons to 24 tons, and elongation or stretching before fracture may be taken at 35 per cent. or 40 per cent. of its length, in a test-piece 2 in. long and of ½ in. sectional area. Special qualities of Bowling and Lowmoor iron give a tensile strength of 27 tons per square inch, and a ductility or elongation represented by 38 per cent. in a test-piece 2 in. long, whilst best Staffordshire iron of 24 tons tensile strength has an elongation of 30 per cent. in a test-piece 2 in. long. In considering the percentage of elongation before fracture, it is necessary to note the length of the test-piece employed, for with a longer test-piece the percentage of elongation will appear proportionately reduced, since the greater part of the elongation is distributed over only a very short length of the test-piece ; thus the elongation of Staffordshire iron, given as 30 per cent. above, would not exceed about 20 per cent. if the test-piece were of the now more usual length of 8 in., instead of the 2 in. quoted above.

The tensile strength of iron plates varies as much as 20 per cent. in the same plate, according to the test-piece is taken lengthwise—that is, in the direction of greatest longitudinal extension, and therefore of development of fibre during rolling—or is cut crosswise from the plate ; a test-piece cut longitudinally may have a tensile strength of from 20 tons to 24 tons per square inch, but a piece cut crosswise will break with from 18 tons to 22 tons ; and thus the Admiralty require in first-class B B plates that they shall have a tensile strength of 22 tons per square inch along the length of the plate, with 18 tons to the square inch in a test-piece cut crosswise of the plate, besides which certain forge tests are specified, and all plates are to be free from lamination and surface defects.

Under the microscope malleable-iron is seen to consist almost entirely of crystals of iron, Figs. 64 and 65. These are irregular in form, as they have interfered with one another during growth. The carbon is present as small detached masses of pearlite, and if the section be at right angles to the direction of rolling in addition, there are many black specks of intermixed slag and oxide. The more thoroughly the metal has been worked the more numerous, smaller, and more evenly distributed will these particles be. If the section be taken parallel to the direction of rolling, the iron is still seen to preserve its crystalline structure ; but in place of the black specks there are long strings of slag or oxide. When the metal is rolled hot the metal crystals are not elongated, since at welding temperature they can rearrange themselves freely, but the particles of slag and oxide are drawn out, and thus produce the fibre. The fibre, therefore, is due to the breaking up of the structure by the presence of these threads of foreign matter, and that is why malleable iron is so much weaker across the grain than with it. The fibre is not a source of strength, except in so far that it shows that the iron has been well worked because mild steel, which has no fibre, is stronger than malleable-iron of the same composition.

Wire-drawing very materially increases the tensile strength of iron.

Upon the differences in mechanical treatment of hammering, piling, welding, and rolling which the puddled ball
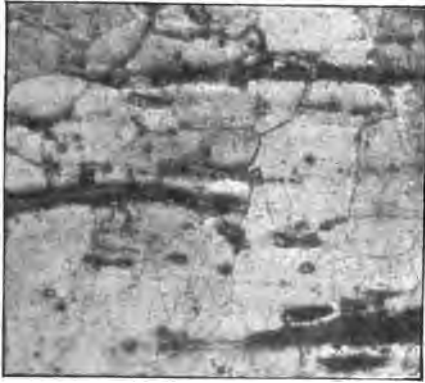
Fig. 64.—Micro Longi-
tudinal Section of
Malleable-iron.
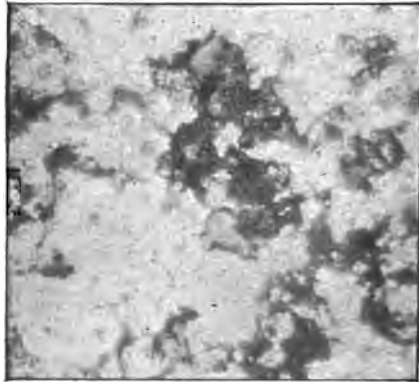
Fig. 65.—Micro Cross
Section of Malleable-
iron.

has received after withdrawal from the puddling furnace
principally depends the commercial classification of malleable-
iron into puddled bar No. 1, merchant bar No. 2, best or No. 3,
best-best, and treble-best qualities or grades. Of these,
puddled bar represents the long flat bars with a rather
rough surface, which, whilst unfit for the smith's use, are
used chiefly for cutting up and piling, as described later, for
the production of No. 1 and the higher qualities of bar-iron.
No. 1 is produced by the blooming of the puddled ball under
the hammer or squeezer, and then passing the bloom so

L

produced without re-heating through the grooves of the roughing and finishing rolls for the production of the required section, which varies with the use for which the bar is intended. It shows no fibre, breaks with a crystalline fracture, and shows fragments of slag and oxide of considerable size scattered through it.

For the production of No. 2 or "merchant bars," the lowest quality of bar iron used by the smith, puddled bar, is cut up at the shears into suitable lengths, and piled into oblong rectangular packets, which are then placed in a re-heating furnace, where they are raised to a welding heat, and in that state passed, with or without previous hammering, through the several grooves in a train of rolls which produce the desired section.

In the manufacture of No. 3, or "best iron," the pile or packet is made in the same manner as for No. 2, except that the top and bottom bars or plates of the pile are formed of No. 2 iron instead of No. 1, or the whole pile may be formed of No. 2 cut up and piled in the same manner as for the production of merchant from puddled bar. The pile is raised to a welding heat, and then again passed through the rolls. This quality corresponds to the best Staffordshire iron often mentioned in engineers' specifications, and is better adapted to the requirements of the smith than either No. 1 or No. 2, owing to its superior toughness and ductility over the low grades.

"Best-best" is a superior quality of bar iron, suitable for chains, anchors, rivets, etc., and is the result of the cutting up, piling, re-heating, and re-rolling of bars of No. 3 iron ; while a further repetition of this process yields the "treble best" iron of the iron-master. The varieties of iron known by the names Best-best-best, etc., are not always made by the system of rollings described above, but often depend on the character of the iron used, Best-best iron being often produced from puddled bar by one piling, heating and rolling.

Malleable-iron is rolled into various "sections" at the mill—round bars, square bars, half rounds, L bars, Z bars, T bars, channels, and many other forms. As each form and each size of each form requires a separate pair of rolls, each mill usually rolls only a limited number of sections, and each firm issues a section book giving the sections it is

prepared to roll without the cost of making new rolls. Rails, girders, and heavy sections are now almost always rolled of mild steel.

" Nail rods " are the square bars used by nail-makers, etc., and are produced by cutting up the ordinary plates of the required thickness in a slitting mill, which consists of a pair of rolls fitted with collars, either turned on the rolls themselves or supplied by loose discs fitted to them. The rolls revolve together so that the collars in one roll fall into the spaces between the collars of the other, thus forming a series of circular cutters which act as shears upon the plate or bar passed between the rolls, and so cut up the metal into a number of small rods or bars.

" Iron plates " in like manner result from the rolling of suitably piled bars, the white-hot pile being first passed through the grooves of the blooming rolls for the production of a square bloom, which is then passed through the roughing rolls, and finally through the finishing rolls, the thickness of the bloom or plate being reduced at each successive passage between the rolls. The order of passage and mode of building up the pile for plates varies with the size of the plates. It is usual to describe all plates of a thickness below No. 4 Birmingham Wire Gauge (abbreviated B.W.G.)—·238 in.— as " sheets," whilst all above such a thickness are called " plates." " Black plates " are the thin sheets intended for tinning, and which, during the process of rolling, are doubled over upon themselves after every re-heating. This doubling is performed in the case of very thin sheets so that sixteen thicknesses are being passed between the rolls at once, before the plates are cut up to their proper and finished sizes. Sheets so produced are classified as " singles," if between No. 4 and No. 20 B.W.G. (·238 in. to ·035 in.) in thickness ; or as " doubles " if between No. 20 and No. 25 B.W.G. (·035 in. and ·020 in.) in thickness ; and as " trebles " or " lattens " if between No. 25 and No. 27 B.W.G. (·020 inch and ·016 inch) in thickness. It is necessary to add that in present day practice steel plates—not iron plates—are employed in the manufacture of tinplate and galvanised sheets.

CHAPTER XIV.

THE PRODUCTION OF MALLEABLE-IRON.

MALLEABLE-IRON may be produced direct from iron ores, or indirectly by first smelting the iron ore and then treating the pig-iron in the open hearth or reverberatory furnace.

The methods for the production of wrought-iron direct from the ores include the Catalan and similar processes, still used to a small extent in the Pyrenees, India, and some other places; the method of the American bloomery furnaces, and some more modern methods.

The methods for the production of malleable-iron by the indirect processes: (a) The treatment of pig-iron in the open hearth, as by the South Wales process; in the Lancashire hearth or Swedish finery, and similar processes; and (b) The treatment of pig-iron in the reverberatory or puddling furnace, this being the process by which the bulk of the malleable-iron is produced.

The direct processes necessitate the use of purer and richer ores and fuels than the indirect processes; since although ferric oxide is reduced at a red-heat by carbon-monoxide, yet the reduced iron is then left mixed with the gangue of the ore; but if the gangue be readily fusible, then the iron sponge produced by this reaction may be consolidated by hammering or squeezing into a comparatively solid bloom, and the scoriæ at the same time expelled. In the direct process readily fusible scoriæ permitting of being thus expelled can only be produced by using rich ores and extracting only a portion of the metal which they contain, the remainder of the iron escaping in combination with the silica and other impurities of the ore, and so producing readily fusible silicates rich in iron. Under these circumstances the carbon does not combine with the reduced iron in sufficient quantity to recarburise it to the condition of pig-iron.

The Catalan process is now little used, but it may be taken as a type of the primitive method for the direct production

of malleable-iron. The ores must be rich and readily fusible, and charcoal cheap and abundant; but even then the product is expensive, owing to the large consumption of fuel—from 3 to 4 tons of charcoal per ton of hammered blooms. Considerable manual labour is required and there is a heavy loss of iron in the slags, which are essentially rich ferrous silicates $(2FeO,SiO_2)$, are not reducible by carbon-monoxide or by carbon at the temperature of the furnace. Owing to the fluidity and low temperature at which ferrous silicate slags fuse, the temperature attained in the furnace is always below that at which carbon combines readily with iron, and this, together with the decarburising influence of the
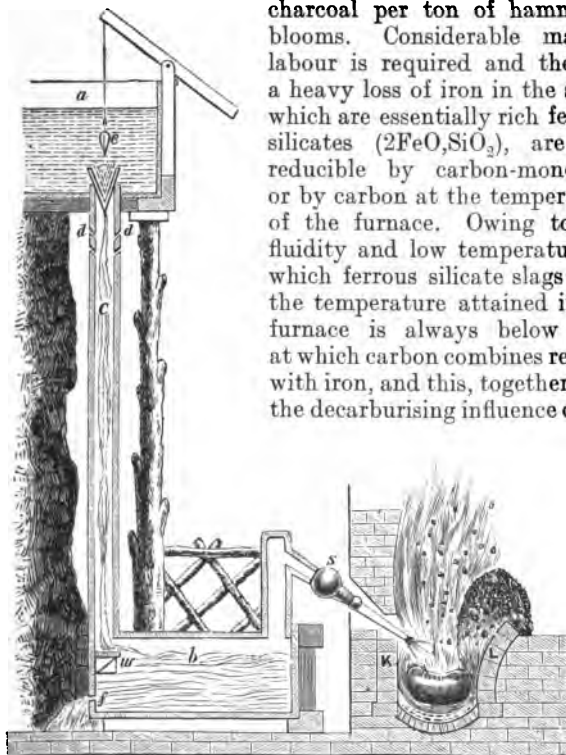
Fig. 66.—Catalan Furnace and Blowing Apparatus, Vertical Section.

slags, prevents the formation of cast-iron in the furnace. Therefore the product is iron; containing only a small proportion of carbon, but often enough to make it distinctly steely; which is not fused, but collects in masses at the bottom of the hearth.

The Catalan furnace (Fig. 66) consists of a quadrangular

hearth, about 3 ft. by 2 ft. 6 in., tapering to 2 ft. 2 in. at the bottom, the back of the hearth, through which the tuyere enters, being formed by the side of the building in which the furnaces stand. The furnace hearth is wider at the top than at the bottom, and is built of refractory masonry set in fire-clay, openings being left in the masonry for the escape of moisture. The working bottom of the hearth is of sandstone or some very refractory rock, and the sides K L are built up of heavy blocks of iron, the outer side L being built so as to form a convex curve. The conical tuyere is of sheet copper and into this the blast-nozzle is inserted ; it is placed at an angle of 30° to 40° with the bottom of the hearth. The blast is supplied by a trompe or water-blowing machine, the blast being always highly charged with water vapour. The process of smelting is begun by clearing out the remains of the last charge and then distributing over the red-hot hearth burning charcoal ; as this burns up the hearth is filled up with charcoal to the level of the tuyeres, after which a sheet-iron division is inserted across the hearth, and more charcoal is added to the compartment so formed nearest to the tuyere, whilst the other side farthest from the tuyere is charged with roasted ore, usually an easily reducible brown hæmatite containing from 40 per cent. to 45 per cent. of metallic iron. The ore is first broken into pieces of the size of an egg, and by raising the partition as required during the filling of the hearth the ore is heaped up on the side opposite the tuyere, and its surface finally covered over with damp charcoal and small ore ; while at the same time the space between the ore and the tuyere side of the furnace is filled up with the larger pieces of charcoal. The blast is now put on slowly ; as the temperature increases the reduction of the metal is effected, the charge at the same time sinking down, and fresh charcoal being added to supply the place of that consumed.

The slag and spongy iron produced collect in the hearth-bottom, the workmen all the time moving the descending pasty materials towards the blast-nozzle, whereby they are more strongly heated, and the slag better separated from the reduced metal. After about five hours sufficient metal will have collected in the bottom of the hearth to form a bloom, when the slag, which has throughout been tapped out at

intervals, is again run out, and the spongy mass of metal is withdrawn to be shingled under the steam-hammer to expel the slag and extraneous matters, and to consolidate the mass by welding together the spongy granular mass into a more solid bloom. Each charge of about 9½ cwts. of ore, containing from 45 per cent. to 48 per cent. of iron, occupies altogether about six hours to work off, and consumes in its reduction about 10¾ cwts. of charcoal, yielding, after shingling, cutting up, re-heating, and again hammering, about 3 cwts. of iron bars. The reactions which take place are quite simple, the oxide of iron is reduced partly by carbon-monoxide and partly by the carbon to iron which separates, or to ferrous oxide which combines with the silica, forming ferrous silicate.

Bloomery furnaces, similar in principle to the Catalan forge, but having the sides made hollow so as to allow of the circulation of water to keep them cool, are still in use in remote parts of the United States and Canada, for the smelting of the rich and pure magnetic iron ores and titaniferous iron sands, the former for preference, since the latter are more refractory. The Bloomery furnace was formerly employed in England, but is now abandoned.

The High Bloomery or Stuckofen furnace, formerly employed on the Continent, occupied a position between the Catalan and Bloomery hearths just described, and the modern blast furnace ; the Stückofen was a small furnace about 15 ft. high, and 3 ft. in diameter at the hearth, with only a single arch at the hearth, which was loosely bricked up when the furnace was at work, and used alike for the insertion of the tuyere and for the withdrawal of the bloom, or sometimes with a single tuyere opposite the arch. The blast was supplied by bellows driven by a water-wheel, and the slag was tapped out from a separate slag-hole at the proper intervals. The furnace was first filled with charcoal, which was ignited at the tuyere hole ; then the tuyere was inserted and the blast turned on as soon as combustion was thoroughly active ; the ore and charcoal were alternately added as required, and in about 24 hours sufficient metal had collected in the form of a bloom on the hearth to require removal, an operation effected by first removing the bellows and the tuyere, and then taking down the temporary masonry which closed the arch through which the bloom of spongy metal

was withdrawn for consolidation by shingling under the hammer. The bloom so obtained was cut up, refined in small hearths or bloomeries with bottoms lined with fine charcoal, and the refined bloom was again hammered out for the production of bars.

Many other methods have been suggested for the direct preparation of malleable-iron, either as a sponge or as welded masses. In the Hursgafel process oxide of iron was reduced by charcoal in an iron cased cupola with a movable hearth in which the bloom could be moved away to the hammers. In the Siemens direct process the ore was reduced by charcoal in a rotating furnace, and was balled up in the ordinary way. In the Chenot process an iron sponge was obtained by heating the ore and charcoal in an externally heated fire-brick retort, the charge being cooled by passing through a water cooled chamber before it left the furnace; and in Blair's process the reduction was brought about by producer gas. These processes were all abandoned when mild steel was introduced, and for so many purposes displaced malleable-iron.

CHAPTER XV.

THE method of producing malleable-iron by the treatment of pig-iron in open - hearth fineries is of considerable antiquity but has now rapidly diminished in importance, and is almost extinct. The usual course is simply to melt pig-iron in shallow hearths, and then to expose it to the decarburising influence of a blast or current of atmospheric air directed upon its surface from an inclined tuyere. Another course is to use white iron approaching in composition to refined metal, and to introduce into the furnace such decarburising agents as hæmatite, hammer-scale, and the like, without any material assistance from the decarburising influence of the blast.

The operations for the conversion of grey pig-iron into malleable-iron upon the open hearth embrace three stages. In the first stage the grey iron is converted into white iron in a coke refinery ; the second stage is that of lifting and breaking up the metal in the furnace, while the third or final stage is that of balling the product. The whole operation may be conducted in two separate furnaces consisting of one refinery, or running-out fire, working in conjunction with two charcoal fineries, or it may be completed in one hearth or fire. The former method represents the mode of procedure in South Wales, whilst the latter constitutes the German or Walloon process of Sweden, etc.

The South Wales process was employed to produce the metal for " coke plates." It consisted in the fusion of good quality pig-iron in a coke refinery or running-out fire, followed by a further fining and working of the refined metal so produced in a charcoal finery ; the product was worked under the steam hammer or helve into large cakes or stamps of from $1\frac{1}{2}$ in. to 2 in. thick, and these are then re-heated in the hollow fire, forged under helves, and rolled into bars ; these latter were then cut up into proper lengths for rolling out in the manner to be subsequently described, into sheets or plates of the required thickness.

The refinery or running-out fire was a small hearth, about 18 in. square, to which a blast of air was supplied through a pair of inclined tuyeres, which is employed for the conversion of grey into white iron preliminary to dry puddling in the reverberatory furnace. Worked in conjunction with the South Wales refinery were two charcoal fineries placed immediately in front of it but at a lowel level, so that the charge of imperfectly refined metal could be, tapped from the bottom of the refinery hearth, and run direct along inclined grooves or channels into the two fineries between which the charge of one refinery was divided.

The charcoal fineries were also small rectangular hearths surmounted by a chimney or stack and supplied with cold blast through a water tuyere. The hearth was formed of cast-iron plates, and the bottom was made hollow in order that it might be kept cool by the circulation of air beneath it ; the side plates along three sides of the hearth were placed vertically, whilst the fourth or working side was made to slope outwards.

In the refinery or running-out fire coke was used as fuel, and upon the hearth, previously charged with coke, there was placed at each charge from 5 cwts. to 6 cwts. of pig-iron, which then slowly melted and collected on the bottom of the furnace, becoming partially decarburised and refined by the oxidising action of the inclined blast. The metal so collected in the hearth was then tapped out from the bottom and divided between two charcoal fineries, which were still at a red heat from the working off of the last charge. The charcoal fineries, after the withdrawal of a charge, were cleared of residual matter before the introduction of a fresh charge from the refinery, and any metal that remained on the hearth was collected into a ball to be added to the next charge. In tapping the metal from the refinery into the two fineries, the slag was kept back as much as possible, but a little always passed into the fineries and quickly solidified on the surface of the metal, from whence it was removed and a quantity of charcoal then thrown over the metal. At this stage the blast was turned on, and the partially solidified metal was broken up by the workman, who then drew the metal towards the tuyere side of the hearth whilst water was lightly thrown over the surface of the charcoal to prevent loss by its burning

away, and more fuel was added as required during the progress of the process. The residual ball of metal collected from the hearth after the withdrawal of the previous charge was now added, and in a little over one hour from the commencement, the workman having in the meantime constantly broken up and raised the metal from the hearth bottom towards the tuyeres, the metal would have " come to nature," as it is termed, and a lump of pasty, malleable metal, mixed, however, with much slag or cinder, collected in the bottom of the hearth, from whence it was withdrawn in one bloom or ball weighing something under 2 cwts. This bloom was forthwith shingled under the steam-hammer or under a helve of about 6 tons weight, for the production of a flat bar or slab 1½ in. to 2 in. thick, which was nicked so that it could be broken up by the sledge hammer into pieces or stamps, weighing about 28 lbs. each. The fracture of each bar was examined, and only such slabs as presented a fairly crystalline and uniform grain of metal were used in the formation of the pile for the finished sheets. During the conduct of the process of fining, it was the practice to tap out the slag or cinder from the hearth two or three times, as might be required. Such slags or cinders were of a highly basic character, containing towards the end of the fining operation as much as 75 per cent. of oxide of iron.

The stamps obtained as above were subsequently piled upon the flattened end, from 12 in. to 18 in. long, of a staff made of a metal similar in quality to that of the stamps themselves. The pile formed by placing about three of the stamps upon the staff was raised to a welding heat in the hollow-fire, and then welded into a solid mass under the hammer, whereupon the slab so formed was nicked on the under side and then doubled upon itself, whereby the top and bottom surfaces of the pile are produced from the same surface of the slab. The pile was again raised to a welding heat in the hollow-fire and again welded under the hammer into a billet, which is taken whilst still hot, sheared from the handle of the staff, and at once rolled into a bar.

The particular method of procedure just described for the production of the hammered bloom was known as the method of " tops and bottoms," from their upper and lower surfaces being produced from the same face of the slab, and these

blooms were afterwards sent to the rolls for rolling out into sheets, of which the upper and lower sides present the same kind of surface.

The hollow-fire for reheating the stamps was a deep rectangular hearth or chamber of brickwork, arched over at the top, whilst in the sides are openings closed by sliding doors. The bottom of the hearth was formed of cast-iron plates, beneath which the air was free to circulate for keeping the plates cool. On the bottom plate was built a layer of fire-brick, and the hearth was not provided with any chimney or stack, but the gaseous products of combustion before escaping to the atmosphere, passed from the hollow-fire through a partition or wall between it and a second chamber in which the pile of stamps was placed for a preliminary heating before it was inserted into the flame of the hollow-fire. The firing door or stoke-hole was on one side of the chamber, and through this door the fuel (coke) was introduced on to the hearth bottom. The chamber was at all times only partially filled with fuel, and the combustion was maintained by a blast of air introduced from an inclined tuyere near to the surface of the fuel. In this manner the chamber or furnace above the fuel was filled with flame, which played around the stamps placed within it for reheating ; the pile did not rest upon the bottom, but was supported in the midst of the flame, in which manner it is raised to a welding heat without coming into contact with the fuel, the handle of the staff all the time projecting beyond the furnace door.

The Lancashire hearth or Swedish finery is also a rectangular closed chamber or hearth, the sides and bottom of which are of cast-iron plates. The hearth communicates by horizontal flues with the stack, and the pig-iron is first placed in them for heating before it is drawn forward into the hearth itself. Through one tuyere is introduced a blast heated to a temperature of 212° F. (100° C.) by passing it through a series of iron tubes heated by the waste-gases of the finery ; the blast is delivered at a pressure of from 1 lb. to 1¼ lbs. per square inch. The method of procedure with the Lancashire hearth is first to charge upon the heated hearth a quantity of charcoal ; then to add from the flues or heating chambers a charge of about 2 cwts. of the pig-iron which has been heated there by exposure to the gases in the flues ;

the blast is then turned on and more charcoal is added, in which manner the metal is slowly melted and trickles down before the blast, so that it is partially decarburised before it reaches the hearth bottom, where it partly solidifies or hardens. The workman is constantly engaged breaking up the metal with his bars and raising it before the blast for further fining and decarburisation. As the decarburisation thus proceeds, the metal becomes less fusible, and the workman is able to raise the whole charge to the top of the fuel in the hearth, and this being accomplished, it is immediately followed by the addition of fresh charcoal and an increase in the temperature by the turning on of more blast, whereby the partially fused metal is again perfectly melted, and thus better separated from the slag with which it is mixed ; and this being effected, the fined metal is collected into a ball upon the hearth bottom, and is then withdrawn from the furnace, shingled as usual, and cut up into suitable lengths for piling and reheating, either in a separate fire or in a gas-furnace. The pile is then rewelded and further treated under the hammer or rolls for the production of malleable bars.

The fuel consumed in this hearth amounts to about 150 lbs. of charcoal per 100 lbs. of bars produced, whilst the process is attended with a loss of about 15 per cent. of the weight of the pig-iron introduced into the furnace or finery.

The Walloon process, like the Swedish-Lancashire hearth last described, is an example of the three operations of melting down, breaking up, and balling of the product in one and the same furnace, as a continuous operation, and is principally interesting as being the method according to which, in Sweden, the famed Dannemora malleable iron is produced. The furnace is a simple quadrangular hearth from 2 ft. to 2 ft. 6 in. wide, and about 10 in. deep ; it is formed of thick cast-iron plates, and is fitted with an inclined tuyere through which the blast is introduced from two pairs of primitive bellows, worked by cams upon a revolving shaft driven usually by water power. The hearth is surmounted by a hood and chimney of brickwork, for taking away the gases, etc., from it. In one side of the hearth, and opening near the bottom of it, is an aperture through which the liquid slags produced by the process are tapped out.

The hearth, having worked off its last charge, is partially

cleaned by tapping out most of the remaining slag, but it is still necessary to leave in the hearth sufficient of the highly basic slag to assist in the decarburisation of the succeeding charge ; for the fining in this process is always conducted in a bath of slag. Besides the slag, there will also remain a residue of incandescent charcoal, and upon this is placed the succeeding charge of from 2 cwts. to 3 cwts. of metal, previously cast into small pigs. The hearth is then filled up with fresh charcoal, and the blast is turned on, at first slowly, but more freely as the process goes on. The metal for refining soon begins to melt, and falls down in front of the blast in its descent towards the hearth bottom ; it thus becomes partially decarburised and purified under the oxidising influence of the blast, the decarburising action being also assisted by the highly basic slags of ferrous silicate, which collect upon the surface of the metal in the hearth. The slags, as before mentioned, are tapped out through the slag-hole as their quantity becomes excessive, only sufficient being retained in the hearth to cover the fluid metal, and promote by its basic character the desired decarburisation of the pig-iron ; but the richer portions of the slags tapped out are collected, and, along with the hammer-scale obtained in the hammering of the bars, are added to a subsequent charge during the first or melting-down stage of the process. A pasty mass of partially-refined iron thus collects in the bottom of the hearth, and the workman, with the assistance of a strong iron bar, then collects the metal into one mass or bloom, and raises it on to the top of the fuel, more fuel being at the same time added and the pressure of blast further increased. In this manner the metal again melts and passes down as before into the hearth, having undergone a further degree of fining or decarburisation, by exposure to the oxidising influence of the blast, so that the metal has by this time assumed a spongy condition. It is again collected into one bloom or ball, and withdrawn from the furnace to be shingled for the expulsion of mechanically-mixed slag and the consolidation and welding together of the spongy mass. The blooms weigh from 1 cwt. to 2 cwts. each, and are cut up at the same heat under the hammer into three or four pieces of suitable lengths, which are then reheated, and again hammered for drawing out into bars.

The melting-down stage of this process occupies from three to three and a half hours, and the whole operation, including balling and shingling of the blooms, requires about five hours. The hearth is worked much hotter than the ordinary charcoal finery, and the loss of metal is from 15 to 20 per cent. of the charge of pig-iron introduced, while the consumption of charcoal amounts to about 150 lbs. for every 100 lbs. of pig-iron treated. During the drawing down of the shingled bloom into bars some five or six reheatings of the metal are necessary, of which the first is effected in the finery hearth itself, during the first or melting-down stage of the process, the shingled bloom being held for this purpose by a pair of suitable tongs in the fore part of the hearth, where the temperature is sufficient to heat the bloom almost to a welding heat ; but the later reheatings are effected in a separate fire.

The exact method of procedure observed in the working of the Walloon process varies somewhat from that described above in different works and localities. Thus, instead of introducing the charge on to the hearth in the form of small pigs or slabs, it is not unusual to prepare white or mottled pig-iron in slabs of 15 ft. or 16 ft. long and 3 in. thick, and when the hearth is filled up with charcoal and the blast turned on, a slab is introduced by resting it on a roller in front of the hearth, whilst its extremity is pushed over the plate in front of the tuyere, and so held in the middle of the hearth at a distance of 9 in. or 10 in. above the bottom. The end of the slab is thus presented to the high temperature of the hearth near the tuyere, and as it melts down it is gradually pushed farther into the hearth until in this manner the amount of metal required to produce a bloom of about 100 lbs. in weight has been introduced. By this method the fining or " coming to nature," is very rapid ; and the workman during the melting down also constantly rabbles the metal with iron bars as it collects on the hearth.

The metal produced in these charcoal or Walloon fineries is of a superior quality ; but it is deteriorated when hot-blast and coke instead of cold-blast and charcoal are employed.

CHAPTER XVI.

ALMOST all the malleable-iron of commerce is now pre-
pared by puddling, a process which was invented by Cort in
1784. It consists in heating the pig iron on the hearth of a
small reverberatory furnace with free access of air till the
carbon and silicon are oxidised out. Cort used a furnace
with a sand bottom, and used white iron, which never became
liquid, but remained during the whole process in a more or
less pasty condition, and this form therefore was called dry
puddling. In the modern form of the process grey iron is
used. This melts perfectly, and the escape of carbon mon-
oxide produces the appearance of boiling. The process is
therefore called wet puddling or pig boiling.

The puddling furnace employed in Staffordshire
(Figs. 67 to 71) has a hearth of the form shown in
Fig. 69, with a low flat arch or roof of fire-brick, z (Fig. 71),
sloping gradually from over the front wall of the fireplace
to the flue at the stack end of the furnace. In the small
single furnaces the roof is higher at the working side over
the door than it is at the opposite side. The fire-
bridge, a, between the hearth, c, and the grate, b, is formed
of a hollow cast-iron frame encased in fire-brick, while the
flue-bridge, n, across the other end of the hearth, separates the
hearth from the flue and the stack. The last-named, y, is
built of common red bricks lined with fire-brick; for one fur-
nace only it ranges from 30 ft. to 50 ft. high, and is strength-
ened, as shown, by angle-irons up each corner, and well braced
together by tie-rods passing around the stack. The stack
is surmounted by a damper connected with a lever and chain,
the latter brought down within reach of the puddler that he
may regulate the draught as required during the working
of the process. The outer, or the side and end walls of the
furnace, are enclosed within strong cast-iron plates d, d
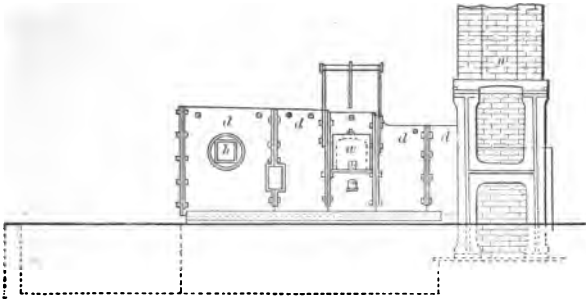
Fig. 67.—Puddling Furnace, Front Elevation.
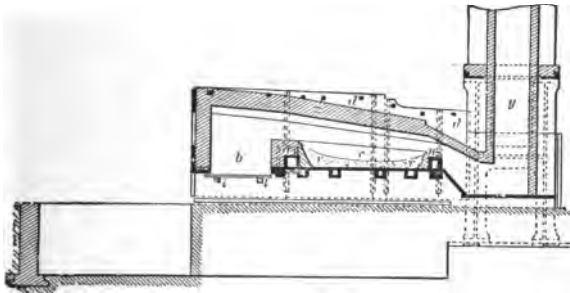
Fig. 68.—Puddling Furnace, Vertical Longitudinal Section.
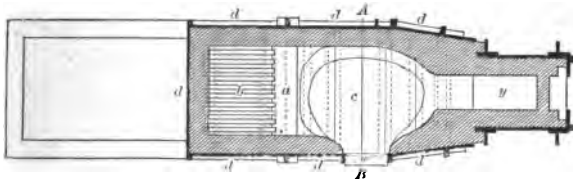
Fig. 69.—Bed of Puddling Furnace, Horizontal Section showing Plan.

(buckstaves), bolted together through suitable flanges, and the plating of one side is connected with that on the opposite side by tie-bolts or rods, passing from side to side over the top of the furnace.

The hearth *c* is about 6 ft. long and about 3 ft. 9 in. wide at the fire-bridge end, and 2 ft. 9 in. at the flue-bridge

M

end. The bridge *a*, between the hearth and the grate-bars is formed of a hollow cast-iron frame enclosed in fire-brick, and the fire-bars are of the ordinary wrought-iron type, readily movable for the removal of any clinker, etc., adhering to them, and they are supported on the usual bearers *t*. The bottom of the furnace bed is formed of cast-iron plates, which are often rebated together, and the joints carefully caulked, the whole being supported upon dwarf pillars, bearers, or brackets, as shown in Fig. 68, to permit of air circulation beneath them. The sides of the hearth are often formed of hollow castings cooled by the circulation of air through them; they are covered at the top and back by
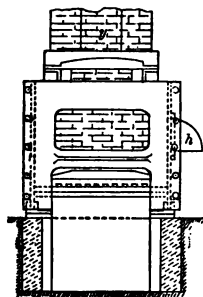
Fig. 70.—Puddling Furnace,   Fig. 71.—Puddling Furnace, Trans-
    End Elevation.   verse Section on Line A B (Fig. 69).
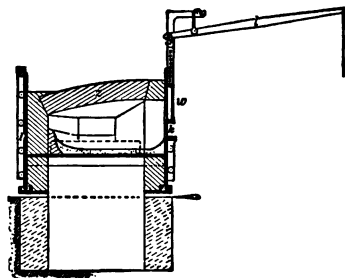
brickwork, which overlaps or projects inwards at the top or upper edge beyond the side castings, so as to form a recess into which the fettling, or refractory lining, is introduced for the protection of the side plates. The depth of the fire-place or grate-bars below the bridge varies with the nature of the fuel to be consumed, a greater depth being required for slightly bituminous coals. But the best fuel for the ordinary grate is a non-caking coal rich in hydrogen, this burning with the production of a long flame which plays over the whole length of the furnace hearth. The area of the grate-bars is from one-third to one-half of the area of the bed, being thus considerably larger in proportion to the area of the bed than is required with the reheating, balling, or ordinary reverberatory furnace. The

firing-hole, *h* (Figs. 67 and 70), is in the front or working side, with its sill-plate about 10 in. above the level of the grate-bars ; it is not, however, closed by any door, but after firing or the introduction of the necessary fuel on to the grate, it is stopped by placing upon the sill of the fire-hole a few lumps of coal, and then throwing over these a shovelful of small coal against the opening into the grate. The working door *w* is placed some 10 in. above the bed of the furnace, and it is closed by a door formed of a large fire-brick tile, slab, or quarry fixed in an iron frame, and suspended by a chain from a lever, *l* (Fig. 71), at whose opposite end is a counterbalance weight and suspended chain, by means of which the door can be readily raised and lowered for introducing the charge and withdrawing the puddled balls ; for these purposes only is the door used, the working of the charge being effected without opening the door by the puddler introducing his bars or paddles through the stopper-hole *k* (Fig. 71), the sides or edges of which serve as a fulcrum for the rabbles during the stirring and working of the charge. In Scotland the furnaces are always worked with a closed ashpit, a jet of air and steam being blown in at the chimney end passing under the hearth and thence to the fireplace.

Large or double furnaces have two working doors, one on each side; they require two sets of men for their manipulation and are equivalent to two ordinary furnaces, but more economical in fuel.

Below the sill-plate of the working door is the tap-hole (Fig. 67), which is stopped with sand during the working of the furnace, and through which the slag or cinder is withdrawn ; the cinder also flows over the flue-bridge during the working of the furnace, and collects at the bottom of the stack. For burning bituminous coal the area of the flue requires to be about one-fifth of the superficial area of the grate-bars, but for anthracite coal the sectional area of the flue is but one-seventh of the grate area. In Scotland no slag is tapped out, but it is allowed to boil over the sill of the door into a " bogie " put to receive it.

Preparing the Hearth.—The working bed (Fig. 68), or lining of the hearth of the puddling furnace, was formerly of sand, but is now always made of refractory substances rich in the oxides of iron, such as hæmatite hammer-scale mixed, or

similar material, such matters aiding by their oxidising
character in the conversion of pig-iron into malleable- or
wrought-iron. The bottom is prepared by first putting on the
hearth a layer of broken slags, tap-cinder or hammer-scale, and
then raising the temperature sufficiently to soften these ma-
terials that they may be spread over the bottom to a uniform
depth of about 3 in.; upon this is placed a layer about 1½ in.
thick of a "fettling" consisting of a nearly pure oxide of
iron, in the form of a soft red hæmatite known by the
name of "puddler's mine," iron scale or purple ore, or
similar material. The side plates are also fettled or covered
with a lining consisting of oxide of iron or of roasted
tap-cinder, or "bull-dog," as it is technically called, which
is rammed well in under the projecting rib of brickwork
or fire-clay slabs covering the top edge of the side plates.
Much importance is attached to the fettling being fixed as
close and dense as possible around the furnace for the pro-
duction of a cleaner iron.

ANALYSES OF THE MATERIALS EMPLOYED AS FETTLING FOR THE
PUDDLING FURNACE.

	Bull-dog.	Purple ore.	Pottery-mine.
Ferrous oxide	3·55	—	46·53
Ferric oxide ..	63·90	95·10	—
Manganous oxide	—	—	2·54
Silicon	15·75	—	—
Titanic acid ..	10·89	—	—
Phosphoric anhydride	·93	—	0·69
Carbonic anhydride ..	—	—	30·77
Sulphur	0·35	0·07	—
Sulphuric acid	—	—	0·04
Iron pyrites ..	—	—	0·34
Copper	—	0·18	—
Lead (as sulphate) ..	—	1·29	—
Lime ..	—	—	2·41
Calcium	—	0·49	—
Alumina	—	—	0·97
Sodium	—	0·29	—
Magnesia	—	—	1·39
Insoluble residue ..	—	2·13	2·27
Water and organic matter	—	—	11·93
	—	99·55	99·88

A good fettling should melt with a clear face. Should it tend to crumble away, and so to become mechanically mixed in an unfused condition with the metal of the puddled ball, it will be exceedingly difficult, if not impossible, to expel it during the hammering or rolling of the bloom into finished iron, and its presence will produce laminations of slag in the finished bar. Lime is sometimes used for fettling, but anything of a quartzose or siliceous nature is to be avoided, and good materials for the purpose are best tap-cinder obtained from reheating furnaces working with cinder bottoms employed in heating the wrought-iron piles for the rolling mills, hæmatite ore free from silica, iron scale, purple ore, or similar materials.

The puddling furnace, when maintained in regular use, requires rebuilding after about six months' work.

Working a Charge.—The actual manipulation of the charge in the puddling furnace may be divided into four stages. During the first or melting-down stage, occupying about 35 minutes, the iron melts and a large proportion of the silicon is oxidised. In the second stage, a comparatively low temperature is maintained, by lowering the chimney damper; the charge requires to be thoroughly mixed with the slag formed during melting down or any oxidising materials added to the furnace, so the puddler during this stage draws down the metal from around the sides, and mixes it with the more fluid metal and cinder in the middle of the hearth. During the third stage the damper is raised, the temperature is inc eased considerably, and violent reaction ensues, marked by the copious evolution of carbon-monoxide, which, escaping through the slag on the surface of the metal, gives rise to the appearance of boiling. In this stage oxidation is promoted by the constant stirring or rabbling which exposes fresh surfaces of the metal to the oxidising influences; at the same time there is produced a fusible slag or cinder consisting of silicates of iron, but containing also excess of ferric oxide, phosphoric anhydride, earthy matters, etc. Near the end of this stage the ebullition gradually subsides, and the surface of the charge. "drops," as it is called, and the whole mass lies in a pasty state on the furnace bed, where it is worked as thoroughly as possible by the puddler, so as to allow the flame to play uniformly over all parts

of the charge. The fourth and last, or balling stage, consists in breaking up the contents of the furnace into some half-dozen balls, which are each rolled towards the fire-bridge of the furnace to receive a final welding heat before being withdrawn to the steam hammer, helve, or squeezer for the expulsion of slag and the production of puddled bar. During the four stages mentioned the damper is raised and lowered several times to regulate the heat, and to adjust the amount of air passing through the furnace.

Supposing the furnace hearth to be hot from the working off of a previous charge, and to contain some of the rich cinder produced during the last heat, the puddling or pig-boiling process is begun by first fettling the sides of the furnace, and then introducing about $4\frac{1}{2}$ cwts. of pig-iron. The working door is lowered, and if necessary made air-tight by luting. The damper is raised, the fire-hole opened, and more coal added to the grate. The fire being thus made up, the fire-hole is again stopped by lumps of coal covered over with coal slack as before, and after an interval of about fifteen minutes the metal begins to soften, and the puddler then inserts his rabble or bar through the stopper hole in the lower edge of the working door, turning over the pigs of metal so as to heat them and the hearth bottom more uniformly ; and as the metal melts he also draws down any portions of unmelted metal from the sides towards the middle of the hearth. In from thirty to thirty-five minutes from the start, the melting-down stage is complete ; then the damper is lowered, and the melted or pasty metal is briskly stirred to incorporate it thoroughly with the oxidising cinder, while hammer-scale or mill-cinder may be added to increase the basicity of the slags, and to combine with the silica produced by the oxidation of the silicon as well as with that introduced in the form of sand, which always adheres more or less to the pig-iron as received from the blast furnace. When the charge has thus become covered with slag or cinder, the damper is again raised and the temperature thereby increased, so that in about forty-five minutes from the start the metal swells and rises rapidly, at the same time appearing to boil, due to the escape of carbon-monoxide resulting from the oxidation of the carbon in the pig-iron by its reaction with the oxides and silicates of iron contained in the basic slag covering the metal

in the furnace. These decompositions are promoted during' this stage by the vigorous rabbling of the charge by the puddler. He constantly moves the metal from the centre of the hearth towards the bridges, whilst at the same time cleaning well around the sides of the furnace.

During the boiling period the escaping carbon-monoxide (CO) burns at the surface of the bath with its character- istic blue flame, and the slag swells up and boils over the sill of the door, and as the decarburisation thus proceeds the mass begins to stiffen, the boiling decreases, the cinder gradually falls or "drops," and the metal "comes to nature," a condition indicated by the appearance of malleable-iron in the form of bright points or specks on the surface of the charge, the points as the process proceeds increasing in size and collecting into pasty masses, when the contents of the furnace are again broken up and mixed by persistent rabbling, and any pasty lumps observed to be sticking to the furnace sides are detached and drawn down towards the centre of the bed, when the heat is again raised somewhat, so as to thoroughly liquefy the slags or cinder, and so promote their separation from the metal.

The last, or balling stage, then ensues, during which the workman detaches a portion of the pasty metal and rolls it over the surface of the furnace bed until it forms a ball weighing from 60 lbs. to 80 lbs., having sufficient cohesion to bear removal from the furnace. Each ball is rolled towards the fire-bridge, where it lies as little exposed as possible to the oxidising current of atmospheric air passing between the working door and the chimney. After the whole charge has been thus collected into about six balls, a final heat is given, after which the balls are withdrawn with tongs, and dragged on to a two-wheeled bogie or truck, which then is wheeled to the hammer, squeezer, or other shingling apparatus. The metal is here welded together into a comparatively solid mass, much slag and cinder being expelled. During the withdrawal of the balls the damper is lowered somewhat, so that a smoky, non-oxidising flame is maintained within the furnace, and the metal suffers but little, therefore, from oxidation and waste during this operation ; but if the puddled balls remain

too long in the furnace the quality of the metal is greatly impaired.

The pigs of iron are charged and piled near the fire-bridge of the furnace, and as the temperature rises they are drawn down by the workman to the centre of the hearth, and there forced beneath the surface of the fluid slag ; the iron sinks down, forming a fluid bath beneath the molten cinder, which protects it from the direct action of the air, unless to bring fresh portions under the oxidising influence, and the oxidation is therefore brought about indirectly by the action of the oxygen in the slag which is continually rabbled into the molten metal.

Upon a new furnace bottom the first charge is made up chiefly of scrap-iron or waste-blooms and refined metal, so that by working this at a high temperature the bottom becomes consolidated and coated with a layer of slag consisting largely of iron oxide, which is but little acted upon by the silicon of the pig-iron subsequently introduced. If grey pig-iron containing much silicon be introduced on to a new bottom as a first charge, the silica resulting from its oxidation acts rapidly upon and unduly destroys the bottom.

The puddler's tools consist only of a long, straight chiselled-edged bar called a " paddle," and a hooked flat-ended bar known as the " rabble," and as these become very hot, each one as it is taken from the furnace is cooled by being plunged into water, and a second one is taken into use.

Pig-iron for Puddling.—Whilst almost any variety of iron could be puddled, that selected, where there is free choice, is a grey iron, almost No. 4, preferably showing a rose—that is, a small portion more coarsely crystallised—in the centre of the fracture. Such an iron will contain about 1 to 1·5 per cent. of silicon.

High silicon is objectionable for several reasons :—(1) It entails considerable waste, as the silica formed will combine with oxide of iron to form silicate. (2) It unduly prolongs the process. (3) The slag formed when the iron is melted down is siliceous, and therefore remains pasty at the temperature of the furnace. It may even remain pasty to the end, when it will not be easily removed by shingling, and the quality of the iron will be injured. When the slag is not sufficiently fusible, the workman says the charge is " cold."

This may be remedied to some extent by the addition of oxides of iron.

If the silicon is too low, the slag will contain an excess of difficultly fusible oxide of iron, or will be dry, and the iron will probably be white, and so unsuitable for " wet " puddling. Phosphorus is an objectionable constituent. About 80 per cent. of the phosphorus present is removed, and the pig-iron should not contain more than ·9, or at most 1 per cent. of phosphorus.

Slags Produced.—Tap-cinder is the slag produced during the puddling process. It is tapped out into wrought-iron waggons after the withdrawal of the last ball of every second heat, or it runs over the sill into the bogies, in which case it is usually called puddlers' cinder. In Scotland the slag is not tapped out except when the furnace is required empty for repairs. During the boil a large quantity boils over the sill, and the remainder is left in the furnace. When scrap-iron is " balled " the slag is nearly pure black oxide of iron. The scrap is, of course, not melted, but is welded together at a high temperature.

In " puddling " the oxidation is effected not directly by the air but mainly by oxide of iron contained in the slag and to some extent by the oxidised materials used in the fettling of the furnace. During the earlier or melting-down stage, in which the silicon of the pig-iron is being oxidised, and the cinder produced is siliceous and contains very little free oxide of iron, there is very little removal of carbon ; but as the process proceeds, and the proportion of silicon in the pig-iron becomes largely decreased, and enough iron has passed into the slag to make it basic, the reaction between the cinder or slag and the combined carbon of the metal increases in activity, and there is the copious evolution of carbon-monoxide and a corresponding decarburisation of the metal, and at the same time a reduction of iron from the slag or cinder.

Sulphur is but imperfectly eliminated from the charge in puddling ; some of it passes into the slag (tap-cinder), where it probably occurs as a sulphide of iron ; but the elimination of sulphur, as far as it goes, appears to proceed somewhat steadily from the beginning to the end of the puddling process. The conditions favourable to the elimination of sulphur from the malleable-iron are : (*a*) regularity of working ; (*b*) the presence

of a good basic slag or cinder, produced by the addition of a fettling rich in oxide of iron, oxide of manganese, lime, etc.; (c) sufficiently lengthy contact of the iron with the cinder before the beginning of the boil, and hence any delay in the process tends to the removal of a larger proportion of sulphur, as also of phosphorus.

The elimination of phosphorus is likewise imperfect. About 80 per cent. of the phosphorus in the pig-iron passes out during puddling, and the tap-cinder produced at the same time always contains a considerable amount of phosphoric anhydride ($P_2 O_5$) (*see* analyses, p. 203).

Manganese, when present in considerable proportion, delays the fining of the pig-iron as it oxidises to a large extent before the iron; it also promotes the better elimination of sulphur from the puddled product. The manganese is to a large extent oxidised early in the process.

Time, etc., of Working.—A "heat" is the time occupied between charging the pig-iron and drawing the last ball of malleable-iron from the furnace, and is generally about $1\frac{1}{4}$ to $2\frac{1}{2}$ hours, the time being longer or shorter according to the purity of the original pig-iron.

The loss in the puddling process varies according to the purity of the pig-iron, for since foreign ingredients are more or less completely removed during the process, it follows that the greater the impurity of the iron the greater will be the loss, but much depends on the skill of the workman. The loss in Staffordshire is from 7 to 10 per cent. and in Scotland somewhat more. The loss is less than that calculated from the impurities removed, as some iron is always reduced from the fettling of the furnace or from oxides added.

Fuel consumption per ton of puddled bars produced is about 1 ton both in Staffordshire and Belgium; about 25 cwts. or 26 cwts. in Scotland; from 24 cwts. to 27 cwts. in the Cleveland district; and about 30 cwts. at Bowling, Farnley, and Low Moor in Yorkshire.

The fettling used during one shift (the charge is 4 cwts. to $4\frac{1}{2}$ cwts.) is from 6 cwts. to 7 cwts. of "bull-dog" and 2 cwts. to 3 cwts. of "blue billy," in Staffordshire.

The tap-cinder, or slag produced during the puddling process, is a highly basic silicate varying in composition at

various stages of the process, but always containing ferrous
and ferric oxide, with manganous oxide, alumina, lime,
magnesia, ferrous sulphide, phosphoric anhydride, and prob-
ably some phosphide of iron. It often yields from 45 to
55 per cent. of metallic iron, existing principally in the form
of ferrous and ferric oxides. The basicity of the cinder is
greatest towards the end of the process as the metal " comes
to nature," since then the oxidation of silicon has been prac-
tically completed, whilst owing to the high temperature still
prevailing within the furnace the oxidation or waste of iron
continues. The cinder expelled during the shingling of the
puddled ball is almost invariably richer in silicon and phos-
phorus, but poorer in iron, than that left on the bed when the
balls are withdrawn from the furnace. During the melting-
down stage of the puddling process, the cinder is the most
siliceous, as is shown by the accompanying analyses, for
during this stage the silicon of the pig-iron is being rapidly
oxidised by the oxygen of the atmospheric air; also the silica
in the form of sand attached mechanically to the pigs of
cast-iron likewise passes at this stage into the slags, in com-
bination with oxide of iron, etc.

The following are analyses of tap-cinder taken at various
periods of the puddling process in an Upper Silesian works,
working upon a charge weighing 4½ cwts. of a mixture made
in the proportion of 24 cwts. of hæmatite pig to 20 cwts. of
white iron :—

ANALYSES OF TAP-CINDER.

	A	B	C	D
Silica	17·13	21·91	19·45	16·29
Ferrous oxide	59·06	46·76	48·04	51·62
Ferric oxide	9·81	12·36	13·48	19·32
Manganous oxide	9·35	15·87	14·40	8·46 ·
Alumina	0·35	0·30	0·34	0·38
Lime	0·69	0·43	0·62	0·61
Phosphoric anhydride	3·40	3·10	4·17	3·78
Iron	52·80	45·02	46·79	53·67

A.—After complete fusion of charge. B.—Before end of refining.
C.—At " coming to nature " of first ball. D.—Slag from hammer
during shingling of first ball.

	A	B	C
Silica	7·71	23·86	11·08
Ferrous oxide	66·32	39·83	63·00
Ferric oxide	8·27	23·75	17·14
Manganous oxide	1·29	6·17	—
Alumina	1·63	0·91	—
Lime	3·91	0·28	—
Magnesia	0·34	0·24	—
Ferrous sulphide	—	0·62	—
Sulphur	1·78	—	0·48
Phosphoric anhydride	8·07	6·42	8·20
Titanic acid	—	—	—
Metallic iron	57·37	47·60	—

A.—Cinder from boiling of white iron (Riley). B.—Staffordshire cinder (Percy). C.—Cinder from pig-boiling.

Modifications of the Process.—Double puddling furnaces manipulated by two sets of men have two working doors, one on each side, through which the metal is simultaneously worked by the puddlers.   The metal produced by them is not likely to be of such good quality as that produced in the smaller single furnaces, owing to the difference in skill between the workmen on the two sides, the furnace working hotter on one side than the other, the longer time that the charge is within the furnace, and the increased volume of air passing through.   But owing to larger charges, amounting to from 10 cwts. to 15 cwts. per heat, as against the 4 cwts. or 4½ cwts. worked in the single furnaces, they have a larger output and a greater economy in fuel and fettling.

It is the practice in some works to add small quantities of Cumberland red hæmatite (consisting largely of ferric oxide) to promote the reactions of the boiling process. Scrap-iron added towards the end of the boiling process is also considered, under favourable circumstances, to improve the product.   Gas furnaces have been tried for puddling, but have never come into extensive use.   The higher temperature obtainable by the gas furnace is no advantage—rather the reverse—in puddling.   When used as a rule the producer is attached to the furnace, and no regenerators are used.

What is known as Parry's process of double or treble puddling consists in taking iron which has been once puddled

according to the ordinary practice, such as ordinary scrap iron, etc., and reconverting it into a kind of pig-iron, by melting in a cupola with coke, and this is then again subjected to the puddling operations. This process is not now used, its only advantage being that it allowed the use of irons higher in phosphorus than could be used for the production of malleable-iron by one puddling.

Various mechanical rabbles have been proposed to aid or supersede the very exhausting manual labour required from the puddler; but these appliances are not applicable to the balling-up of the charge, which has still to be done by the fore-hand at the furnace, and the weight of the charge is accordingly still limited by the power of the workman to ball it up. Mechanical rabbles have not, therefore, come into general use, although they enable the puddler to work somewhat larger heats, and occasionally to effect a slight economy in the working.

Revolving furnaces were also introduced to relieve the puddler of a part of his very arduous labour. In these the hearth consists of a revolving cylinder rotated by steam power. They were expected to produce malleable-iron more economically and of greater homogeneity than by the older fixed furnaces, but these expectations have not been fully realised. The introduction of revolving furnaces appears to date from the Messrs. Walker and Warren's furnace of 1853. Among the more or less successful forms of revolving hearth of more recent date are those of Danks, introduced in 1869, of Sellers and Siemens, each in 1871, and of Crampton, in 1872 and 1873. In these furnaces the hearth revolves in a vertical plane, whilst in others, as in those of Pernot, Godfrey and Howson, etc., it rotates in a plane either horizontal or only slightly inclined to the horizontal.

Waste Heat.—The puddling furnace is very wasteful of heat as owing to the short hearth the products of combustion leave the furnace at a very high temperature. In modern works these gases are passed through the flues of steam boilers, and thus enough steam is raised to supply the needs of the works. The boilers are of the usual Lancashire type, and may be placed either at the end of or above the furnace. The latter is the more usual position, and one boiler is heated by the waste heat from two adjacent furnaces

CHAPTER XVII.

REFINING PIG-IRON AND DRY PUDDLING.

PIG-IRON that is to be made into malleable-iron by the process of dry puddling, as distinguished from wet puddling or "pig boiling," has first to be refined into a partly decarburised and desilicised white or refined iron. In all puddling processes, pig-iron is converted to malleable iron by oxidation; but in dry puddling this oxidation is almost entirely dependent upon the action of the atmospheric oxygen, whereas in the "wet" process, the slags are rich in iron oxides which exert an oxidising action. Dry puddling is applicable only to the working of white iron because this in passing from the solid to the liquid state assumes a soft pasty condition highly favourable to oxidation by the oxygen of the air. White iron from the blast furnace is rarely used, because it is liable to contain a considerable quantity of sulphur.

The refining of pig-iron now under consideration is, therefore, only preliminary to the puddling of the metal in the reverberatory furnace. It consists in melting pig-iron, and directing upon its surface a blast of atmospheric air from several inclined tuyeres, whereby the silicon in the pig-iron is largely oxidised. The silica unites with ferrous oxide to yield a highly basic slag of ferrous silicate containing also some of the phosphorus and sulphur present in the original pig-iron. The iron is now a white or partially purified refined metal, capable of being more readily and quickly converted into malleable-iron in the puddling furnace, owing to its decreased fluidity, and its greater purity. The refined metal may be run directly from the refinery to the puddling furnace, but it is more usual to cast it into forms easily broken up into pieces suitable for introduction into the furnace. It must be understood that whilst the object of the Swedish and German fineries already described was the production of malleable-iron direct, the product of the English refinery now being considered is only the production of a white iron

which must be treated in the puddling furnace before it becomes malleable-iron.

The Finery.—The English refinery or running-out fire (Figs. 72 and 73) consists of a strong cast-iron frame-
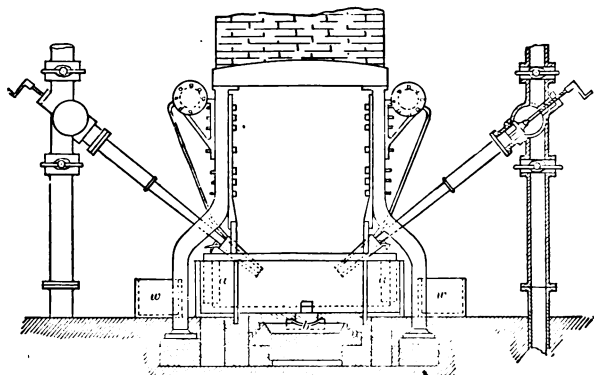
Fig. 72.—Refinery for Converting Grey into White Iron, Elevation.
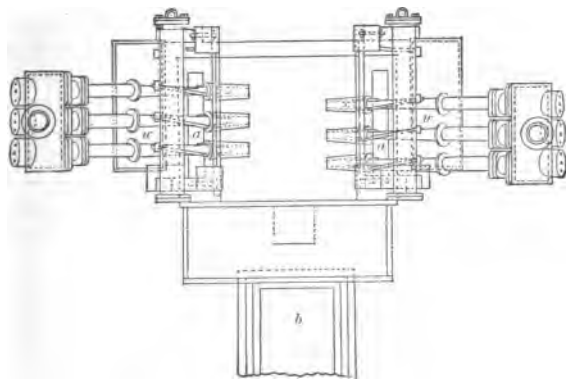
Fig. 73.—Plan of the Refinery and of the Mould for the Refined Metal.

work, surmounted by a low brick chimney or stack from 16 ft. to 18 ft. high. The hearth is about 4 ft. square and from 15 in. to 18 in. deep, bounded on two sides and at the back by cast-iron water blocks,

a, a, through which blocks water circulates. The front
side of the hearth is closed by a cast-iron dam-plate, con-
taining the tap-hole from which the metal and slag flow
into the casting-pit or pig-mould *b,* about 12 in. wide and
14 ft. to 16 ft. long. This pig-mould is in front of the refinery,
and rests longitudinally upon the edges of two long cast-iron
or brickwork cisterns, through which water flows to assist
the cooling of the refined metal, both by cooling the mould
and by supplying the water which is thrown over the surface
of the heated metal in the mould. The water in these cisterns
is maintained at a level of about 1 in. below the underside
of the pig-bed or mould. To facilitate still further the breaking
up of the plate of metal, there may be a projecting rib in the
bottom of the mould to produce a groove and line of weakness
in the casting. The bottom of the hearth is formed of blocks
of dressed sandstone about 12 in. thick, resting upon brick-
work or masonry. Above the side water blocks and
carried upon lugs, are the cast-iron tuyere plates $2\frac{1}{2}$ in; thick,
containing openings for the introduction of the two or three
blast nozzles or tuyeres upon each side of the hearth. The
water tuyeres are usually from $1\frac{1}{2}$ in. to $1\frac{3}{4}$ in. in diameter,
and are inclined downwards at an angle of from 30° to 35°.
The blast is supplied at a pressure of from 2 lbs. to 3 lbs. per
sq. in., according to the nature of the coke employed ; and
the tuyeres are arranged so that they direct their blast towards
the space between the two tuyeres on the opposite side,
thereby distributing the blast more uniformly over the surface
of the molten metal ; each nozzle has a regulating valve for
adjusting the supply of blast from each tuyere during the
working of the charge. *w w* are water troughs or boshes into
which the waste water from the tuyeres is delivered, and in
which the workman cools his tools during the working of the
charge. The back of the furnace between the base of the
stack and the water blocks is closed by wrought or cast-iron
doors hung to the side frames, and the front above the dam-
plate is also closed by a sliding door, connected with a lever
by which it can be readily raised or lowered. A dust-plate
is also usually fixed on the dam-plate to facilitate the filling
and working of the fire.

In the Yorkshire refineries two tuyeres only are employed,
both on the same side of the hearth. The hearth is 4 ft. by

3 ft. 4 in., and is 1 ft. 6 in. deep ; it is surrounded by water cooled blocks, and the refined metal is cast in sand moulds into cakes about 3 in. thick. In some of the smaller refineries only one blast nozzle is used, it being introduced at the back of the furnace.

When the charge is made up of selected pig-iron, old castings and other scrap, etc., the refinery is distinguished by the term " melting-down " ; and when the molten pig-iron is run direct from the blast furnace into the refinery as "running-in."

The refinery works continuously—that is the hot hearth after tapping out a charge is immediately prepared for the next. When starting a new hearth or after a stoppage, some broken sandstone is spread over the floor and a fire made in the centre ; coke is added through the folding doors at the back of the furnace, and a light blast is turned on ; then the charge of pig-iron, scrap, and coke is introduced by piling on the materials in alternate layers, until the whole charge, averaging about 2 tons of metal in the larger furnaces, has been made up, when more fuel is added to the top of the pile, and the full blast turned on. Such a charge requires about 6 cwts. of coke for its refining, and the process occupies from three to four hours, grey iron taking slightly longer than white iron. The refining is accelerated by adding basic slags, cinders, hammer-scale, etc., which act as oxidising agents and slightly increase the total yield of iron, since the carbon of the pig-iron is partially oxidised by the oxygen of the oxides of iron present in the scale or cinder, and an equivalent amount of iron is at the same time reduced and added to the yield.

The first effect of the heat in the newly-erected or repaired refinery is to soften the sandstone and glaze the surface of the hearth. The pig-iron of the charge begins to melt after about one hour, and the iron trickles down through the mass of coke on to the bottom of the furnace, where, in from 90 to 120 minutes, the whole of the charge collects, and so lies fused beneath the coke. More coke is now added, and the blast is continued for another half-hour or a little more, during which time more silicon from the pig-iron is oxidised, producing silica, which, together with an additional amount of silica derived from the ash, etc., of the fuel, combines with the ferrous oxide (part of the iron oxidised by the blast) to produce a highly basic and readily fusible slag or cinder

N

approaching to monosilicate of the formula of a $2FeO\ SiO_2$ = Fe_2SiO_4, containing from 40 to 60 per cent. of iron, and presents when cold the very dark-blue or black colour and the vitreous, lustrous fracture of usual cinders rich in iron. Such a slag has a powerful oxidising influence upon the molten metal beneath it, and thus under the joint influence of slag and blast, the silicon with smaller quantities of carbon, sulphur, and phosphorus and the greater portion of the manganese present in the original pig-iron are oxidised, as indicated by analyses below of the original pig-iron, and of the refined metal obtained therefrom. More fuel is added until the desired degree of fining has been effected.

ANALYSES OF REFINERY CINDER OR SLAG.

| | Dowlais (Riley). | | Bromford Crystallised cinder. (Forbes). |
	Ordinary cinder.	Crystallised cinder.	
Ferrous oxide	65·52	54·94	61·28
Silica	25·77	33·33	22·76
Manganous oxide	1·57	2·71	3·58
Alumina	3·60	5·75	7·30
Lime	0·45	1·19	3·41
Magnesia	1·28	0·50	0·76
Sulphur	0·23	—	0·46
Ferrous sulphide	—	0·27	—
Phosphorus	1·37	0·99	—
Copper	—	traces	—
Percentage of iron	50·96	42·84	47·66

ANALYSES OF REFINED IRON.

| | Ebbw Vale (Noad). | | Bromford (Dick). | France (Regnault). | |
	Pig-iron.	Refined iron.	Refined iron.	Pig-iron.	Refined iron.
Carbon .. Graphite	2·40	0·30	3·07	3·00	1·7
Silicon	2·54	0·32	0·63	4·50	0·5
Sulphur	0 22	0·18	0·16	—	—
Phosphorus	0 13	0·09	0·73	0·2	—
Manganese	0·86	0·24	trace	—	—
Insoluble matter ..	—	—	0·14	—	—
Iron	—	—	95·14	92·3	97·8

When the refining has been carried far enough the slag and metal together are tapped out into the cast-iron mould, *b* (Fig. 73). The slag (see the analyses above) floats on the metal, and remains fluid after the surface of the metal has become partially solidified ; thus the slag can be tapped off into moulds placed at the lower end of the mould, *b,* while the plate of refined metal is the more rapidly cooled, and rendered also more or less hard and brittle by throwing a quantity of water over its surface.

The plate of fine metal, refined iron, plate metal, or simply " metal," as the product of the refinery is variously called, is from 1 in. to 3 in. thick, 12 in. wide, and from 12 ft. to 14 ft. long. It is grooved along its under side, and being brittle, can be easily broken up into pieces suitable for ready transport to the puddling furnace, where it is converted into malleable-iron. The metal presents a bright silvery-white fracture, the lower part of the slab affording a compact radiated or columnar structure, while the upper portion presents a dull and cellular appearance on fracture.

In this process of refining pig-iron, the loss of iron is somewhat greater and the consumption of fuel is about 20 per cent. in excess of what is required when the metal is taken in the fluid state direct from the blast furnace ; but the average loss may be taken as equal to 10 or 11 per cent. of the weight of the pig-iron operated upon. The loss is greater in refining hot-blast than it is with cold-blast pig-iron, because the former contains a larger proportion of silicon, phosphorus, sulphur, manganese, etc.

In the ordinary melting-down process about 24 cwts. of good grey iron yield 1 ton of refined metal, the fuel consumption being about $2\frac{1}{2}$ cwts. of coke ; and about 136,000 cub. ft. of blast per ton will be required for white iron, or 153,000 cub. ft. for grey iron. The weekly produce of a refinery with six tuyeres working upon grey iron ranges from 80 to 100 tons, and with white iron 150 to 160 tons. By running the fluid metal direct from the blast furnace into the refinery, about 22·3 cwts. of common forge, or 21·1 cwts. of good grey iron, will yield one ton of refined metal, the coke consumption being only about 2 cwts. ; it will require only 94,000 cub. ft. of blast per ton of metal treated.

Dry Puddling.—The furnace employed in dry puddling is

little smaller than that used in the boiling process, and there is no tap-cinder or iron ore in the fettling or lining of the hearth. Formerly the bottom of the furnace was made simply by covering the iron plates with a layer of sand, which was then thinly glazed over with slag; but now the furnace bottom is lined with a 1 in. or 1½ in. thickness of oxide of iron, formed by working a ball of scrap-iron in the strongly oxidising atmosphere of the furnace, the oxide of iron formed being spread evenly over the bottom whilst the furnace is still at a high temperature.

The charge of white or refined iron is placed around the sides of the furnace bed, leaving the centre empty until the metal begins to soften; then the damper is lowered to prevent the metal from becoming perfectly fluid. In its pasty condition the charge is drawn down into the centre of the hearth, where it is broken up and rabbled, so as to mix it with the oxide of iron already produced by the oxidation of the pasty iron, and with that now added to the charge in the form of hammer-scale. The rabbling continues from the running-down to the balling-up of the charge; a vigorous reaction ensues, the carbon and impurities becoming oxidised; in consequence carbonic oxide escapes, whilst the other impurities of the pig-iron are oxidised and largely enter the tap-cinder.

The progress of the decarburisation, " coming to nature " or " drying " of the charge, is indicated by the decreased fusibility of the metal, and other indications similar to those described under pig-boiling present themselves. This stage having been carried to the required degree, the damper is raised, and a higher temperature produced for the balling-up of the metal.

Owing to the smaller quantity of silicon and other impurities in the refined iron treated in dry puddling, the duration of the process is shorter than in pig-boiling, and the production of slag and the fuel consumption are less, and the oxidation is largely brought about directly by the air. Dry puddling is only economical in fuel so long as white or refined iron can be used, and the process is attended by a greater waste of iron than occurs in pig-boiling; whilst unless comparatively pure ores have been employed in the production of the pig-iron to be treated, the malleable-iron resulting from this process is also inferior in quality.

Best Yorkshire Iron.—Dry puddling and its preliminary refining are now almost abandoned in this country, except for the manufacture of best Yorkshire iron, for which they are still in use. Best Yorkshire iron is prepared from pig-iron made in furnaces supplied with a cold blast (cold-blast iron). This is then refined in a hearth, and the refined metal is then puddled. The puddling furnace is small, the charges worked being about 3 cwts., and the time occupied is about one hour. The furnace is provided with a small chamber under the chimney (the dandy), in which the iron is heated before it is passed on to the hearth of the furnace for puddling.

The high quality of best Yorkshire iron does not depend on the materials employed or the process used, so much as on the extreme care which is taken at every stage that no imperfect material shall pass. As this iron is about twice the price of ordinary bar iron the makers can afford to take special care in the manufacture.

CHAPTER XVIII.

THE term "forge" is applied in iron works to the department containing, besides the puddling furnaces, the shingling, blooming, and rolling machinery employed in the production of puddled blooms, slabs, or rough bars from the puddled ball which comes from the furnace.

The shingling or blooming machinery for treating the puddled balls consists of helves, or hammers, and of the puddling rolls or forge-train, which consists of two pairs of rolls, through which the shingled blooms are passed without any re-heating for conversion into slabs or puddled bars about 3 in. wide, ¾ in. thick, and 16 ft. long, or into plates averaging from 6 in. to 15 in. wide, if intended for rolling subsequently into plates or sheets.

The "mill" is a department in which the blooms, slabs, rough bars, etc., received from the forge, are cut up, piled, re-heated, again welded and finished by the mill-rolls into various classes of merchantable iron, such as merchant bars, rods, rails, plates, sheets, or other finished forms.

The shingling and blooming machinery consists of various types of squeezers, helves, and hammers. The helves and hammers act, of course, by the impact or of a falling weight, whereas the shingling by squeezers is effected by a direct compressive or squeezing force. The steam hammer is now generally used for shingling purposes, to the exclusion of the older forms of helve and squeezer.

Squeezers are either reciprocatory or rotary. The single alligator or crocodile squeezer has two broad flat jaws ; the lower one (the anvil) is fixed, whilst the upper one forms one end of a heavy cast-iron lever pivoted on a gudgeon or axis forming the fulcrum of the machine. One extremity of the oscillating jaw is coupled by a connecting rod with a crank or its equivalent. In this manner the upper jaw, which has a toothed under surface, opens and closes upon the lower fixed jaw. The shingler introduces the hot puddled ball

into the open end of the jaws farthest away from the fulcrum, and gradually rolls the ball over towards the fulcrum of the crocodile after each stroke of the machine. At each stroke the bulk of the puddled ball is reduced by the escape of fluid cinder, which flows away from the mass over the sides of the lower jaw or anvil, and by the consolidation of the metal. Finally the compressed ball is formed into a slab or bloom about 5 in. in diameter and 18 in. long. At the extreme outer end of the jaws the movement is sufficiently great to permit of the bloom being placed on end, and compressed endwise, so as to shorten or upset the bloom, and square up the ragged ends. The bloom, when finished at the crocodile, is still sufficiently hot for introduction into the puddling
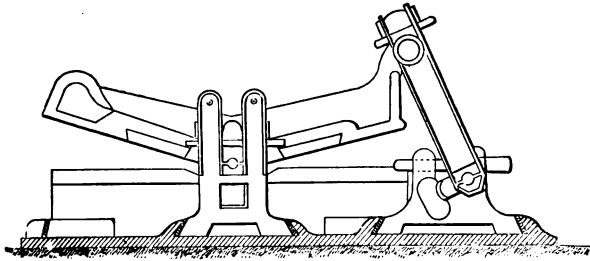
Fig. 74.—Double-acting Crocodile Squeezer, Front Elevation.

rolls for drawing down into puddled bars. The crocodile squeezer makes about 60 strokes per minute, and each ball receives about twenty or twenty-five compressions during its conversion into the puddled bloom. Whilst for heavy blooms squeezers are much more ·efficacious than· hammers, for those dealt with from the puddling furnace the hammer is quite satisfactory. In the forge, therefore, hammers are now always used. Fig. 74 shows a double-acting crocodile squeezers.

Hammers of various classes are employed in the forge for shingling the puddled ball, and occasionally for the working of the finished iron, into the various classes of blooms, billets, forgings, etc., required for the rolling mills and by the engineer. In the older forges the tilt and helve hammers are still to be found, although in modern forges the steam hammer is more generally employed, even for shingling purposes.

The tilt hammer is not commonly used for shingling purposes, as it does not generally exceed 5 cwts. in weight, and works at a high speed, but it is still employed in some parts of Sweden for drawing down blooms into bars, etc. It consists of a wooden lever, strengthened with wrought-iron hoops, and having at one end a heavy sledge-hammer, whilst the cam which works the hammer operates at the opposite or tail end of the lever, the fulcrum being formed by the two arms of a trunnion ring resting on a vertical timber framework placed between the hammer-head and the cam, but nearer to the latter than to the former. As the cam, which is a revolving wheel with twelve or fourteen projecting teeth or wipes, revolves, the wipes press down the short end of the lever, and so raise the hammer-head until the lever is so far depressed that the wipe on the cam slips from the end of the lever, when the hammer then descends by its own weight, and falls upon the work on the anvil. The force and rapidity of the fall are further increased by the introduction of an elastic piece of timber or spring board beneath the short arm. As the cam revolves and the next tooth comes around, it repeats the same operation, and the strokes of the hammer thus follow in quick and regular succession. The end of the lever is shod with iron at the point where the wipes bear. The bottom anvil is of wrought-iron fitted into a heavier mass of cast-iron.

Helve or lifting hammers are of two types, and are made from 30 cwts. to 10 tons in weight; they are still used for shingling in forges where the steam-hammer has not yet been introduced. In one class of helve the cam acts upon the heavy cast-iron lever at one extremity, whilst the fulcrum is placed at the other extremity, constituting the nose or frontal helve, as illustrated in Fig. 75. In the nose or frontal helve, the arm or lever is lifted up as the cam revolves, and is then allowed to fall by its own weight upon the puddled ball placed on the anvil beneath. Into the head of the arm the wrought-iron hammer is dovetailed, and keyed so as to permit of ready removal for the renewal of the faces, as is frequently required. Such helves as are still in use in a few places in Staffordshire, etc., for shingling are from 5 to 6 tons in weight, and the cam, which is about 5 feet in diameter, and fixed upon a continuation of the fly-wheel shaft, has

five teeth or wipes, so that the helve makes five strokes for each revolution of the cam, in which manner the helve makes from 80 to 100 strokes per minute, and the maximum lift of the head is from 16 in. to 20 in.

The belly helve, owing to the cam being generally fixed beneath the floor level, and acting also between the head and the fulcrum of the machine, gives a greater space around the anvil for the manipulation of the puddled ball than the frontal helve.

Steam Hammers.—The steam hammer is now generally preferred to the helve for shingling purposes, since its blow can be regulated according to the work to be done, by throttling the escape of steam to the exhaust, whereby a cushion of steam is preserved beneath the piston of the hammer as it descends
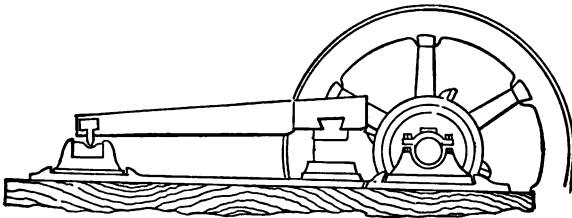
Fig. 75.—Nose or Frontal Helve, Front Elevation.

upon the work, thereby diminishing its velocity and the weight of its blow ; but with the helve the head is always lifted to the same height, and such control as this is impossible.   More- over, the heavy blows of the steam hammer consolidate the metal more quickly and expel the cinder more effectually because the work is done more quickly and more cheaply, while the bloom is still at a high temperature, and if desirable the hammer can be worked so slowly as to be practically a squeezer, so that the metal can be "humoured" in a way that is impossible with a helve hammer.

Steam hammers are somewhat differently constructed according to the special work to which they are to be applied. Thus the smaller hammers adapted to the forging and drawing down of bars generally consist of a single cast-iron standard, in front of which the piston and hammer-head descend on to the anvil.   Supported upon the top of the standard is a vertical

steam cylinder of which the piston rod passes through a gland or stuffing box in the cylinder's lower cover, and is attached to a heavy block or tup which thus ascends and descends with the piston, as the steam is admitted to or escapes from the cylinder. The rotation of the piston and tup is prevented by planing a flat side upon the piston rod and making the stuffing box of a corresponding shape, or the tup is made to work in a guide on the face of the hammer standard. The cylinder is provided with suitable valves connected with levers, by small movements of which the workman can control readily both the ascent and descent of the hammer tup. These hammers are made so that the hammer tup and piston are lifted by the admission of steam beneath the piston, and then allowed to descend upon the work by opening the valve, and so allowing the steam from beneath the piston to escape freely to the atmosphere. A much more powerful hammer is formed by admitting steam upon the top of the piston during its descent, as well as exhausting the steam from the under side of the piston.

In the larger hammers of 30 cwts. and upwards the single standard of the hammer is replaced by two standards, between which the tup ascends and descends. For shingling purposes hammers in which the aggregate weight of the falling mass of tup, rod, and piston is from $1\frac{1}{2}$ to 3 tons are in most frequent use. Fig. 76 shows a double-acting steam hammer.

The foundations for steam hammers are required to be most substantial. They are usually formed first of a layer of concrete, or of concrete on wooden piles driven as far as possible into the earth ; upon the concrete are placed cast-iron bed-plates of weights proportionate to the size of the hammer ; or, in heavy hammers, it is usual to alternate heavy cast-iron plates with balks of oak timber arranged in various ways, and upon this foundation are finally fixed the heavy anvil-block or blocks, of cast-iron, into which the working bottom anvil block is fitted by a dovetail joint and wedges in the same manner as the top anvil or block is fixed in the tup of the hammer. The bottom anvil block for a 10-ton double-acting hammer weighs about 110 tons, whilst the superstructure of hammer and base plate of the same hammer weighs only about 80 tons.

Forge-train.—The rolls for converting the shingled bloom

of malleable-iron into puddled bar, or into merchant bars, etc., form part of the plant of the forge and mill departments respectively. The train consisting of two pairs of rolls, used in the forge, is known as the puddling rolls ; whilst the train of two stands of rolls for the production of sections, plates, and other finished iron or steel, is fixed in the mill, and known as mill rolls.

The puddling rolls or forge-train consists of two pairs of cast-iron rolls placed in one line. The pair of rolls placed at the left of the train are known as the roughing rolls, and in the forge-train they are from 3 ft. 6 in. to 5 ft. long, and from 18 in. to 22 in. in diameter, with a series of oval, Gothic, or diamond-shaped grooves turned upon their surface. The first groove is roughened by cutting indentations upon its surface with a chisel, so that it may the better take hold of the shingled bloom when
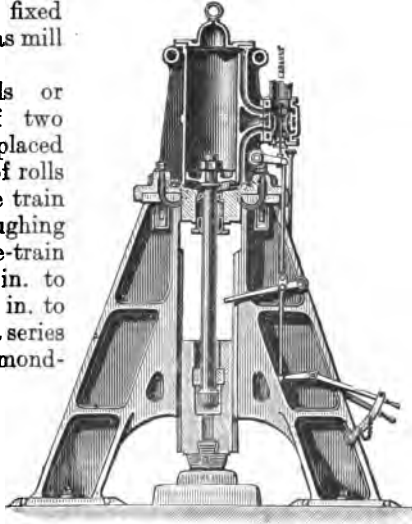
Fig. 76.—Double-acting Steam Hammer, Front Elevation.

it first enters between the rolls. The first two or three grooves of the roughing rolls are Gothic-shaped, whilst the others are diamond-shaped, and the depth of the grooves also diminishes from left to right along the rolls. The two rolls of each pair are placed one above the other in the same manner as the mill rolls (Fig. 77), and the necks or bearings of the rolls are supported upon brasses, in massive cast-iron housings or standards A (Figs. 77 and 78). The lower roll runs in a line with the driving-shaft of the engine ; whilst between the engine and the mill is a pair of spur or helical toothed pinions B (Fig. 77), of the same diameter as the rolls, which pinions run in their own standards or housings D. The outer

end of the lower pinion is connected direct with the engine shaft, whilst the other end is coupled to the bottom roll by connecting spindles *b, b,* and coupling-boxes *a, a,* as illustrated in Figs. 77 and 78. The upper pinion is coupled in the same manner with the top roll, and is driven by the lower pinion ; so that the rolls like the pinions thus revolve in opposite directions. The distance between the rolls is adjusted by screws *s, s,* passing through nuts in the top of the housings, the lower extremity of the screws acting upon the top bearers *k,* on the neck of the rolls, and the screws are worked down either by hand, through levers upon the heads of the screws, or fed down automatically by an arrangement of gearing. To protect the necks and steps of the roll bearings from the cinder, etc., expelled from the metal during its roughing-down in these rolls, a narrow groove is often turned in both the top and bottom rolls, and a cinder-plate of sheet-iron inserted to prevent the cinder from passing towards the necks of the rolls. In front of the bottom roughing roll and extending for the full width between the housings is a serrated fore-plate or rest, for receiving the shingled bloom from the bogie, upon which it is brought from the squeezer or hammer to the rolls.

The connection between the engine and the bottom pinion of the forge-train, as also between the pinions and the rolls and between the rolls themselves, is made by breaking-pieces or spindles, *b* (Figs. 77 and 78), and coupling-boxes *a,* which are made somewhat weaker than the necks of the rolls, so that whenever the mill encounters any unusual resistance or sudden strain these spindles break before any serious damage can be done to the forge-train. The necks of the rolls project beyond the bearings in the housings, and have the same form as the end of the spindle *b,* whilst the coupling-boxes or wabblers *a* (Fig. 77) fit easily upon the projecting end of the roll, as also upon the end of the spindle. When the spindle with its two coupling-boxes has been placed between the two rolls or other necks to be coupled, the coupling-boxes already placed upon the spindle are moved half their length over the wabbler end of the roll or pinion, as the case may be, so as to connect the two ; whilst the slipping back of the boxes during the working of the mill is prevented by the introduction of wooden or iron stops, laid in the hollow of

the spindles and between the ends of the coupling-boxes ; the stops are secured in position and prevented from falling out during the revolution of the rolls by twisting an iron . wire or band around them and the spindle.

The finishing rolls of the forge-train are similar in their housings to the roughing rolls just described, but their grooves are flat channels, and form, when the pair of rolls are together, the required section for the puddled bar. The grooves diminish in depth from left to right, and those in the upper roll stand over those in the lower. In front of the bottom roll is a fore-plate or rest, and also guides for the easier insertion of the bloom from the roughing rolls into the grooves of the finishing rolls.

The puddle rolls receive the hot puddled blooms direct from the squeezer or hammer, and the blooms are first introduced into the largest groove at the extreme left of the roughing rolls. After passing through them the bloom is returned over the top of the rolls, to be again inserted from the front side into the next groove to the right, and so on in succession through the several grooves of the roughing rolls as required to produce the desired bloom. The bloom so obtained is passed onwards to the finishing rolls of the train, where it is passed in like manner successively through the several grooves or holes of this pair, until long flat bars with more or less ragged edges and a rough surface, and from 3 in. to 7 in. wide, and from $\frac{3}{4}$ in. to $1\frac{1}{2}$ in. thick, according to requirements, constituting puddled bar, are produced. From this, merchant bar is prepared, as already described by the cutting up and piling of puddled bar, reheating it to a welding heat and again passing it through the rolls. If the puddled bars are intended for cutting up and piling into piles for the production of plates, then the width of the puddled bar is made from 7 in. to 15 in.

The forge rolls revolve at the rate of from fifty to eighty revolutions per minute, the quicker speeds being more general in Wales, whilst the slower speeds are more prevalent in Staffordshire and the Midlands. The rolls, as also their necks or bearings, are kept cool by running a continuous but regulated supply of water over them.

CHAPTER XIX.

THE mill equipment includes the furnaces in which the metal has to be heated for rolling and the rolls. The mill rolls are employed for the production of finished iron from the puddled bar. The bar is cropped or cut up in suitable shears, and piled in various ways to form a parcel or packet, which is then inserted into a balling or reheating furnace for raising it to a welding heat, after which it is passed through the mill rolls to weld together the constituent bars of the pile, producing thereby No. 2 and higher grades of merchant iron, rods, bars, sections, etc., the quality depending upon the number of times the bars have been cut up, piled, reheated, and rewelded. The piles employed in the production of the heavier sections vary in size from 4 ft. 6 in. long and 12 in. square to 18 in. long and 3 in. square, but the latter are exceptional, such light sections being rolled from " billets," which are merely short lengths of square bars of a section and weight required to produce the finished product.

The **mill rolls** or mill train (Figs. 77 and 78), for rolling merchant iron, like the forge train, consists of two sets of rolls, of which the roughing or billeting rolls average about 6 ft. 6 in. in length and 22 in. in diameter, whilst the finishing rolls are somewhat smaller in diameter and shorter in length ; but their length and diameter vary considerably in different works, being much influenced by local or other special requirements. The rolls run in bearings carried in housings as described for the puddling rolls, except that the finishing rolls in the mill are also provided with tightening and adjusting screws n (Fig. 79) for keeping them more accurately in position as the bearings wear down, in addition to the setting down screws s in the head of the housings for adjusting the distance apart of the rolls. The necks l of the rolls do not rest in continuous brass bearings, but bear upon four small brasses carried respectively in the bearers or riders k, k_1
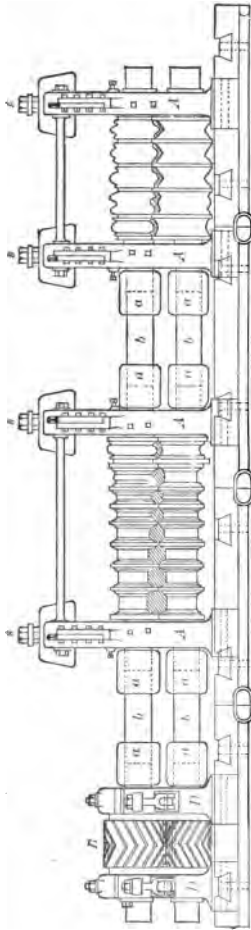
Fig. 77.—Mill Rolls for Rolling Sections, Rails, etc., Front Elevation.
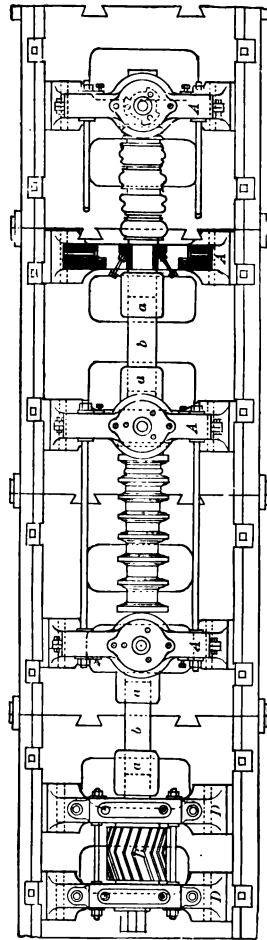
Fig. 78.—Mill Rolls with One Standard in Section, Plan.

and the side chocks *m*, the side brasses being adjusted by the set screws *n*. The top roll is carried by a bolster, k_1, supported at each end from the top of the standard by the two bolts *p*, which pass through the rider *k*, and the side chocks, *m* ; or in other cases, instead of passing through the

top of the housing, the bolts *p* are on the outside of the housings and suspend the bearer *k* from two lugs cast for this purpose on the side of the standards. The power of the engine is transmitted through a claw-clutch or crab on the end of the engine shaft, and thence through a spindle to the lower pinion of a pair which run in their own standards, while the wabbler ends *a* of the pinions (Fig. 77) are connected by spindles and coupling-boxes or wabblers with the ends of the roughing rolls ; the other projecting or wabbler ends of the two roughing rolls being in like manner coupled by boxes and spindles with the
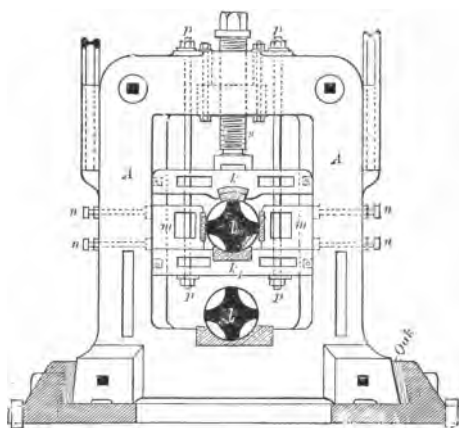
Fig. 79.—Roll Housing, or Standard for Mill Rolls, End Elevation.

near ends of the two finishing rolls ; or, as is sometimes done, only the lower finishing roll is connected by a spindle with the lower roughing roll, and motion is then imparted to the top finishing roll by gearing fixed on the outer projecting ends of the two finishing rolls. This latter method of driving from the lower roughing roll only has the advantage of permitting the use of larger or smaller roughing rolls, as may be desired, without interfering with the finishing rolls.

In rolling small and light sections, which are therefore whilst hot very flexible and difficult to keep from bending and twisting during the operation, it is usual to provide an apron or fore-plate in front of the rolls, as also guide jaws

for directing the work straight as it enters the rolls, in which manner much of the twisting is avoided, and the train so provided is hence known as a " guide train," and the iron produced therein as " guide iron."

In rolling sections, bars, etc., the bottom roll is always provided with " stripping-plates ; " these are plates of iron resting at one end in a cross-bar supported by the roll standard, and at the other end upon the roll itself. They are shaped to fit into the several grooves of the rolls, and are also bevelled off at their lower edge so as to fit on the circumference of the roll, with their upper surface tangential to the surface of the roll. They thus act as chisels or wedges in clearing the bars from the grooves of the bottom roll, thus preventing " collaring," or wrapping of the bars around the bottom roll.

In two-high trains revolving constantly in one and the same direction it is, as already explained, necessary to return the work over the top roll from the back to the front of the rolls, after each pass of the work between the rolls ; and thus much time and labour is lost, to overcome which either " three-high rolls " or mills that can be reversed at each passage of the work have been largely adopted for the mill-trains.

For lifting light work to the top of the upper roll in the two-high non-reversing mills, it is usually sufficient to receive it as it issues behind the rolls upon forked levers suspended from a travelling carriage above, and by which the workman raises the bar to the required level, so that the roller-man in front of the rolls may seize it with his tongs and draw it forward on to the fore-plate of the mill for insertion into the next hole of the rolls. Where heavy sections or plates are rolled, some two-high plate mills have movable fore-plates or feed-plates fitted to the mill, so that as the work issues from behind the rolls it is received on this plate, which is at once raised to the required level by a single-acting engine, or by an arrangement of levers worked either by hand or by power, or the table is elevated by an hydraulic cylinder and ram. The work thus elevated is drawn over the top rolls to the front side of the mill, ready for its reintroduction between the rolls.

Reversing Rolls.—In the case of reversing mills the reversal is effected either by reversing the engine itself, as introduced by Mr. Ramsbottom for the rolling of rails, etc.,

o

or by the introduction of hydraulic, friction, or other clutches and gearing on the engine shaft, whereby the rotation of the rolls is reversed whilst the engine continues its revolutions always in the same direction.

Three-high rolls consist of roughing and finishing rolls, each of which is a combination of three rolls in its own pair of housings. With three-high rolls the mill is usually driven
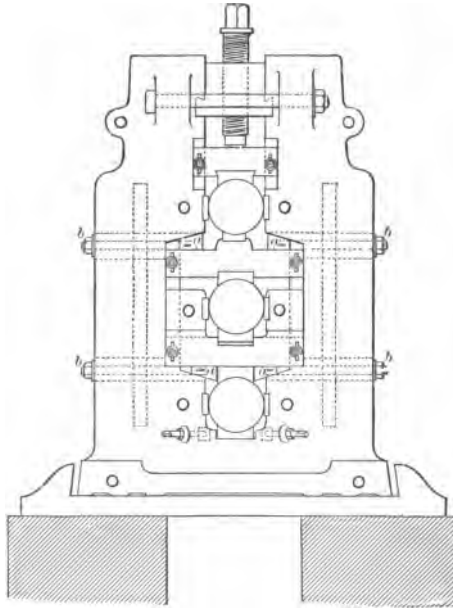
Fig. 80.—Housing for Three-high Rolls, End Elevation.

from the middle roll, although under special circumstances it may be driven from the lower one. Thus the rolls are driven through three pinions, the wabbler ends of the pinions being coupled as before by spindles and coupling-boxes with the ends of the three rolls ; and the middle roll therefore revolves forward with the lower one, and backwards with the upper one, or *vice versâ*, according to the direction of rotation of the middle roll, so that the work thus passes backwards and forwards alternately through the grooves or

holes between the middle and bottom rolls, and between the middle and upper rolls respectively. The work, as it issues from the grooves in the lower rolls, is received and lifted in the manner already described to the level of the holes between the middle and upper roll, after passing through which the bar is received on the other side by a corresponding arrangement, and immediately lowered to the level of the lower pair of rolls.

In three-high mills various mechanical arrangements are made for adjusting the distance of the top and bottom roll from the middle one. In two-high mills, the top roll is movable for the purpose of adjustment, but in the three-high system either the middle roll may be fixed and the top and
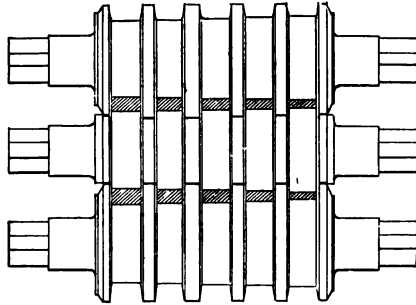
Fig. 81.—Three-high Rolls for Merchant Iron.

bottom rolls run in adjustable bearings, or, as in Fig. 80, the bottom roll is fixed, and the middle and top rolls are carried in adjustable bearings.

In most American three-high trains for merchant iron, the top and bottom rolls are grooved (*see* Fig. 81), and the middle roll has the collars turned upon it. This plan requires shorter rolls for the same number of passes, and obviates turning over the bar after each pass, the grooves opening alternately upwards and downwards, so that the fin formed in the top groove in the upper pass is smoothed down by the solid bottom of the groove in the upper pass. An objection to the three-high mills is the necessity of providing between the middle and top rolls suspended and balanced stripping-plates for turning the work out of the grooves as it issues from the rolls.

Plate Mill.—The general arrangement of a plate mill is the same as that of the ordinary mill train, except that the rolls are plain cylinders of uniform diameter, and that the top roughing roll is balanced by counter-weights as
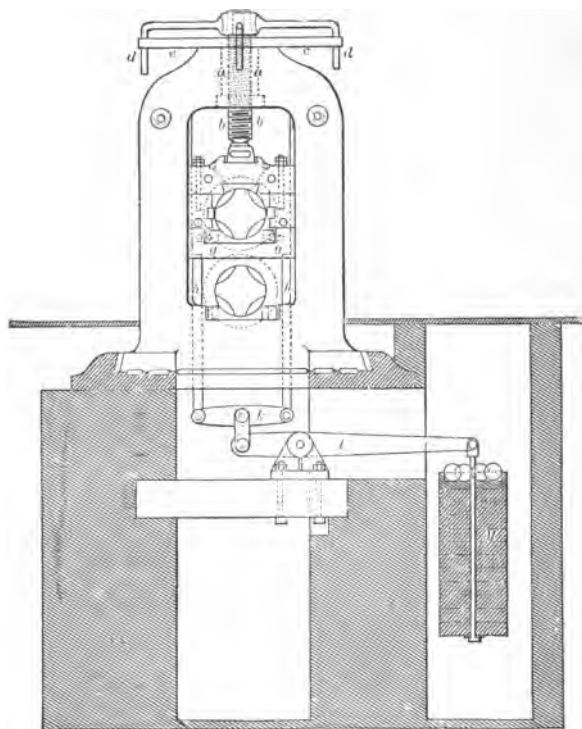
Fig. 82.—Plate Mill Housing, showing Balance Weights for Top Roughing-roll, End Elevation.

in Fig. 82, whilst the top finishing roll runs freely, being revolved only by the friction of the work passing between it and the bottom roll. The plate mill has two pairs of rolls, varying in different mills from 20 in. to 36 in. in diameter and from 4 ft. to 9 ft. long. The roughing rolls are grain-rolls —that is, cast from tough cast-iron, not chilled on the surface

—whilst the finishing rolls are chilled castings, the depth of chill varying between ½ in. and 1¼ in. All the rolls run in brass bearings and are carried in housings, in the top of which are fitted nuts *a*, and setting-down screws *b*. When the setting-down screws are moved by hand, a large hand-wheel *d* is fixed to the head of each screw, the degree of rotation being indicated by a pointer and a graduated ring *c* fixed on each housing, so that the workman may see that both screws are set down to the same degree, so giving the same thickness to both edges of the plate as it passes between the rolls. Spur and bevel gearing governed by a self-acting arrangement for feeding down uniformly both screws at once is applied to the larger mills, this self-acting motion being necessary when tapered plates are being rolled, in order that the rolls may be uniformly and gradually fed down to give the desired decrease in thickness from end to end of the plate as it passes between the rolls. The top roughing roll rests in a bolster *g*, supported upon bars *h*, which are connected with a system of levers *k*, *l*, and balance weights, M (Fig. 82), suspended beneath the bed-plate or foundation of the rolls. These balance weights suffice to lift the top roll as the feed-screws are turned back, and so keep it constantly in contact with its top bearing, thus preventing the fall of the top roll on to the bottom roll as the bloom or slab leaves the rolls after each passage between them. A pile, bloom, or slab of 4 in., 8 in., or 10 in. or upwards in thickness can be introduced between the rolls. The finishing rolls have generally much less work put upon them than the roughing rolls; they usually reduce the plate by only a fraction of an inch, but they take out the buckling and any irregularities of thickness from the rough plate. The top finishing roll runs loose in its bearings and revolves solely by the friction of the plate passing beneath it, and the upper roll thus drops down through the thickness of the plate on to the lower roll as the plate leaves the rolls after each pass. The distance apart of the rolls is diminished at each pass by screwing down the feed-screws, and in non-reversing mills the plate is lifted by a movable table arrangement and passed over the top of the rolls to the front side, to be again inserted between the rolls.

To overcome this loss of labour and time reversing mills have been adopted. The plates pass between the rolls from

front to back, and are received there on a horse or platform inclined towards the rolls, and fitted with friction rollers, over which the plate moves. When the mill is reversed the plate is easily pushed forward with tongs or bars down the horse and into the rolls ; on the front side of the rolls it is received on a bogie, which runs out with the end of the plate as it issues from the mill. The rolls are reversed and the screws set down at each pass, until the desired thinness has been attained, upon which the plate is conveyed to the mill floor near to the shears, where it is laid down to cool, and straighten if necessary.

In plate-mills and two-high mills generally the circumference of the top roll in contact with the metal is made slightly larger than the bottom roll, so that the upper surface of the metal is extended a little more than the under surface. Thus the leading end of the plate tends to curve downwards as it leaves the rolls, and collaring around the top roll is prevented. Stripping-plates are fitted to prevent collaring around the bottom roll.

The metal extends in rolling almost wholly in the direction of its length ; hence the bloom, etc. is first passed between the roughing rolls in the direction of its breadth so as to extend it to the full width required.

The ends of a rolled plate are cut, as may be necessary, to reduce the plate to the requisite dimensions.

Iron plates formed from piles built up in a special manner are passed through the roughing rolls in the directions of their length and breadth alternately, until the full width has been attained, after which the rolling is continued entirely in the direction of length. The object is to get the strengths of the plate in the two directions as uniform as possible.

Sheet mills resemble the plate mills, except that the rolls and mechanism are lighter. The sheet mills of Birmingham and of South Wales have rolls from 18 in. to 22 in. in diameter and from 3 ft. to 6 ft. long, running at from thirty to thirty-five revolutions per minute. For producing the larger sheets the billets are about $1\frac{1}{4}$ in. thick, and two of them are usually rolled together, passing between the rolls crosswise from the front side and then being returned by the back-hand over the top of the rolls to the front side, whilst the screws are set down to reduce the space between the rolls after each passage

of the work. Thus the plates are reduced to about $\frac{1}{3}$-in. thick, and then they are placed one upon the other and passed together through the rolls for a few times, until finally two sheets, each about 3 ft. 6 in. wide and 5 ft. long are produced. The sheets are then annealed at a red-heat and, after reheating, are again returned to the rolls in pairs and further extended ; if the sheets are to be very thin each one is again doubled upon itself crosswise, reheated, and again rolled. Then the sheets are put on one side to cool, after which they are sheared to size, again annealed, and finally made into bundles for sale.

Annealing.—The annealing is effected by placing the sheets in wrought-iron or steel annealing pots or boxes, which, when filled, are run into a reverberatory furnace and allowed to remain there for about twenty-four hours. Large annealing pots hold 18 tons of sheets, each 10 ft. long. They are charged by piling up the sheets on a base-plate, over which the inverted pot is dropped, the joint of the cover and base-plate being luted with clay. The whole is then inserted into the furnace, and heated as above ; the pot requires about four days to cool down after withdrawal from the furnace. Very much smaller annealing pots than the above are in use in South Wales.

Universal Mills.—The so-called universal or Belgian mill for rolling plates and bars has two horizontal rolls *a* running in standards, and geared together ; in addition a pair of vertical rolls *b*, *b* (Fig. 83) work in front of the horizontal rolls. The top horizontal roll is balanced by counter-weights *c*, after the manner of the plate-mill, so as to keep the roll against its top bearing. The distance between the rolls is regulated by screws rotated by two hand-wheels ; or the screws are connected by gearing with a shaft *e*, actuated by one wheel *d*, which is rotated either by hand or by steam power. The vertical rolls work upon slides, and can be moved towards each other or apart from one another by a right- and left-handed screw *k*, working in nuts carried upon the bearings of the two vertical rolls, and actuated by means of the worm-gearing *h*, moved by a hand-wheel *m*, which is under control of the workman. The vertical rolls are rotated from the driving pinion, *g*, of the mill through spur and bevel gearing so arranged that the bevel wheels slide along their shaft, and thus follow the lateral movement of the rolls as these are either separated or brought closer together. The work as it passes through these rolls

is compressed on the edge by the vertical rolls and on the flat between the horizontal rolls ; so that a mill of this class may be employed for the production of a considerable variety of sections of flat bars by simply adjusting the horizontal and
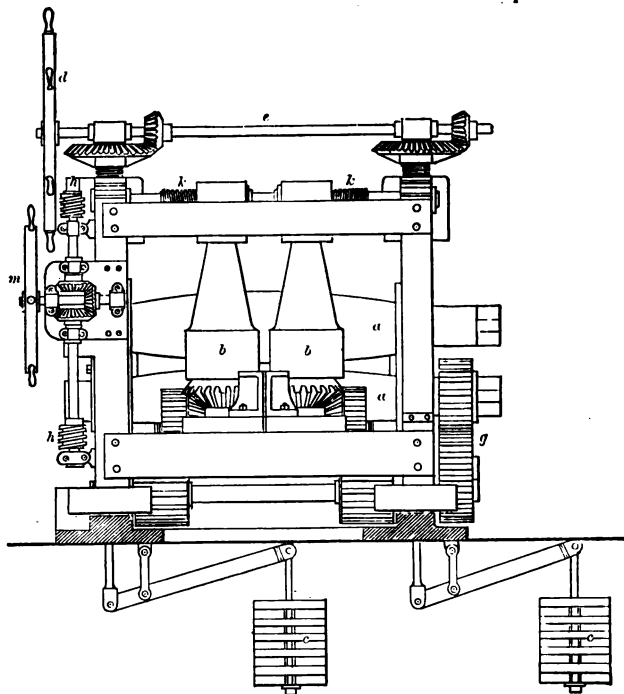
Fig 83.—Universal or Belgian Rolling Mill.

vertical rolls to the thickness and width respectively of the bars required.

Speed, etc., Mills.—The size and speed of mills vary with the work to be done. Reversing mills for rolling heavy plates with rolls of from 20 in. to 36 in. in diameter make only 25 to 30 revolutions per minute, the smaller mills for merchant bars or guide iron, with rolls from 12 in. to 18 in. in diameter, generally run at the rate of from 80 to 125 revolutions per minute ; the

still smaller mills, such as those for rolling billets into wire, with rolls from 8 in. to 12 in. in diameter, run at from 250 to 500 revolutions per minute. The roughing rolls in reversing mills for rolling iron rails, and having rolls from 20 in. to 24 in. in diameter, run at about 30 revolutions per minute, the speed being much higher when the mill is non-reversing. Mills rolling steel usually run 25 per cent. or 30 per cent. faster than the corresponding mills working upon iron, and owing to the much lower temperature to which steel is heated, more power is required for rolling a given section in steel than in iron. It may be noted that in rolling rails, when the rail leaves the finishing rolls it is carried along upon a series of five power-operated rollers in the floor to a circular saw 8 ft. in diameter, where the ends are cut square and to the exact length. After the rails have become cold, they are straightened in a horizontal straightening press, and then passed on for drilling at each end under double-drilling machines, as required for the fish-bolts.

The usual time occupied in England in rolling a double length of steel rail with six roughing and five finishing passes is a little more than two minutes. In the American mills, driven feed-rollers like those just mentioned for receiving the rail from the mills are employed both in front and in the rear of the rolls wherever heavy work is manipulated.

The **slitting** mill for the production of " slit " or " nail rods " consists of a pair of rolls, housed in the usual manner, but made to act as a compound shearing machine, for which purpose collars acting as circular cutters are turned upon the rolls, or separate steel collars or discs are fitted upon a spindle or arbor with stops between them. The discs on the upper roll falling into the space or groove between the collars on the lower roll, but leaving sufficient space for the thickness of the metal. Flat bars are divided or cut during their passage through the rolls, and are delivered at the rear of the mill as a series of bent and twisted strips or rods of rectangular section, requiring to be straightened by hand and made into bundles, when they are ready for sale to the nail forgers. The bars, on entering the slitting mill, are steadied by guides, and the cutters are cooled by water continually running over them.

Mill Engines.—Rolling-mill engines vary considerably in

type and power; they are made direct-acting, high-pressure, either non-condensing, condensing, or compound, while both vertical and horizontal types are employed; but non-reversing, high-pressure, non-condensing engines with heavy fly-wheels are usually adopted for the smaller mills rolling merchant and guide iron in two-high or three-high mills; whilst for the heavy mills producing iron and steel plates, rails, heavy angles, sections, and the like, reversing mills are the more usual.

Reversing mills are usually driven by horizontal engines either of the high-pressure or of the compound type; such engines being fitted with either friction clutches, hydraulic clutches, differential gear, etc., the rolls can be reversed whilst the engine moves constantly in the same direction; or, as is more general, the engine itself for reversing mills is reversed at each pass of the work between the rolls, according to the plan introduced by Mr. Ramsbottom, and hence generally known as the Ramsbottom reversing mill engine, but it is altered or modified to suit the special conditions of different mills. Reversing engines are now made also somewhat extensively upon the compound type.

Piling Bars.—The method observed in building up or piling the bars and slabs of malleable-iron into packets or piles for reheating and welding together into a solid mass varies for every class and quality of work. For the production of No. 2 merchant iron the bars of No. 1 are cut up into lengths, and the pieces so obtained are piled into a stack some 6 in. or 8 in. square, from 30 in. to 40 in. long, and about 4 cwts. in weight. The joints of the several bars do not fall one above the other, but always cross or break joint. The pile so formed is held together by an iron hoop, and after being raised to a welding heat in the reheating or balling furnace, the pile is passed through grooved rolls in the manner described; or the welding together may be effected by hammering and subsequently drawing the hammered bloom into bars by means of a bar or guide-mill. For smaller bars the piles of about 100 lbs. each are only about 18 in. long and from 3 in. to 4 in. square, formed from flat bars about $\frac{3}{4}$ in. thick; but billets are more generally used for these smaller sizes.

For making iron plates the pile is formed by placing the bars in layers, each layer crossing the underneath one; the

top layer is covered like the bottom with a slab about 1½ in. in thickness, and of a length and width suitable to the dimensions of the particular plate which it is designed to produce. Scrap and crop-ends are also built up along with the puddled bar in these piles.

For iron rails, about 18 or 20 pieces of puddled bar, each about 3 in. wide and ⅝ in. thick, are arranged along with scrap-iron in the middle of the pile, while the top and bottom iron slabs are formed either of a plate of No. 2 iron from 6 in. to 7 in. wide and 1 in. thick, or of a puddled bloom which has been already doubled over upon itself, and previously rewelded. In rolling such a pile it must be so passed through the various holes of the rolls that these top and bottom plates are eventually rolled into the two heads of the rail.

For producing small round or square bars of merchant iron, the piles, after heating and hammering or rolling into square bars of 1½ in. or 2 in. square, are cut under the cropping shears into billets of from 12 in. to 24 in. in length, and these billets are afterwards reheated and then rolled in the finishing rolls into small bars.

It is usual to form the top and bottom members of piles of single bars or slabs, because butt joints unless covered by other bars or plates do not weld properly. Thus, in piles for rails the top and bottom layers were formerly made up of slabs produced by the doubling over and welding together under the hammer of two or more puddled blooms, without the same having been previously rolled into bars in the puddling mill; but the hammered blooms so produced were reheated and rolled into the desired slabs. The ends of the bars, also because' of the difficulty of welding, should be cut square, and the bars should be as free as possible from scale, dirt, rust, or other foreign matters which interfere with the welding, and consequently with the homogeneity of the finished bar. The piles, as formerly made in South Wales, for rolling into rails weigh about 15 cwts. each, and four of these are placed at one time into the reheating furnace, and afterwards rolled into blooms, which are then again reheated, and again passed to the mill. In nine passes through the rolls such blooms become finished rails ready for cutting to length, and subsequently drilling or punching for the fish-plate bolts.

Shearing the Bars.—The crop-ends of rails, angles, heavy sections, bars, etc., are cut off immediately the work leaves the rolls, the metal being still hot. The rail is drawn from the rolls to the front of a circular saw of from 4 ft. to 8 ft in diamet r, running at the rate of from 800 to 1,200 revolutions per minute. The saw is carried in a swinging frame
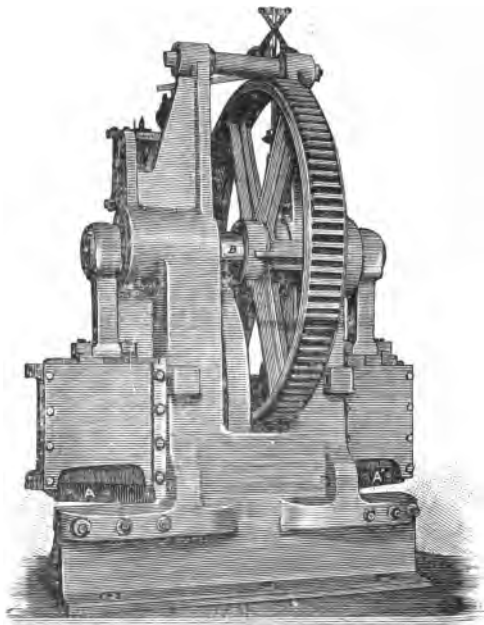
Fig. 84.—Shears for Cutting up Puddled Bars and Slabs.

which can be moved out towards the work by a rack and pinion arrangement controlled by the workman, which thus, amid a shower of sparks, rapidly cuts across the work, leaving the ends comparatively clean and square.

Puddled bars (Fig. 84) are also generally sheared hot with crocodile shears into lengths suitable for piling, etc., and these shears are likewise employed for cutting up the bars that are not cut up by the hot saws, as also for cutting off the rough or

crop-ends of puddled, finished, or other bars. Occasionally, for dressing the sides and edges of plates and shearing them to size, are used larger and broader-faced guillotine shears (Figs. 85 and 86). For the smallest and lightest plates or sheets the crocodile or alligator shears are still in use.

The crocodile, cropping, or alligator shears—three names for the same tool—has two jaws, the lower, D (Fig. 86), of
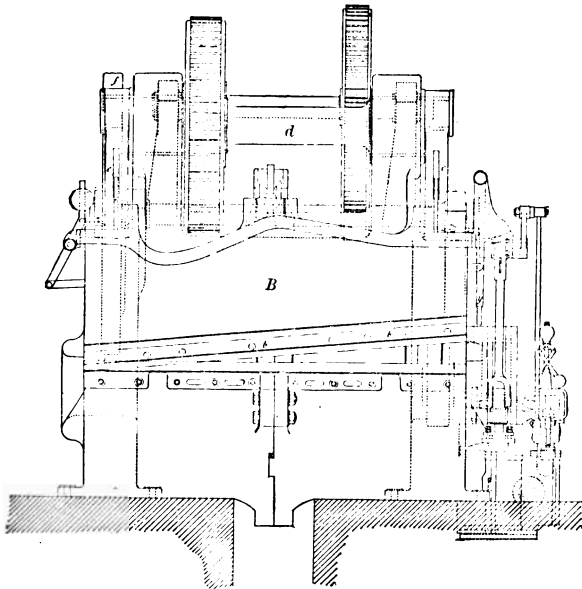
Fig. 85.—Plate Shearing Machine, Front Elevation.

which is fixed, and forms part of the cast-iron foundation or is secured to it, whilst the other jaw E oscillates on a pin passing through the jaw, and supported in bearings on the casting of the lower jaw. The upper jaw E has the form of a heavy straight or bent lever, one end of which is fitted with a blade F of steel, hardened on the edge to act as the cutter, whilst the end of the lever on the opposite side of the bearing is coupled by a connecting rod G, with a crank H, or with an eccentric. With the heavier shears it is usual

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to derive the power from a small independent engine, upon whose shaft is a crank which is coupled by a connecting rod with the end of the moving jaw of the shears. The lower jaw also has a cutting edge of hardened steel, which works opposite to the blade on the fixed jaw, and these knives are readily replaced as they wear out. Fig. 86 shows a crocodile shears as applied to a powerful plate shears, where it is em-
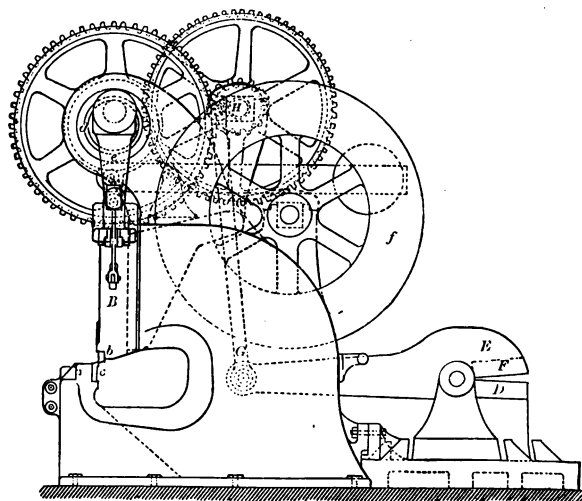
Fig. 86.—Plate Shearing Machine, with Crocodile Scrap Shears Attached, End Elevation.

ployed for cutting up the scrap produced from the shearing of plates, etc.

A form of powerful guillotine shears which has replaced somewhat the older crocodile shears, is represented in Fig. 85. This machine cuts on each side of the centre, having two pairs of blades, A, A^1, driven from cranks at either extremity of the same shaft, B, exactly in the manner of the ordinary shearing machine.

The shearing machine shown by Figs. 85 and 86 is employed for shearing heavy plates. It has a cast-iron framework, made in halves and bolted together. On the face of the standards, and working upon prepared surfaces, is the

apron or slide B, in the lower edge of which is fitted the steel-faced cutter *b*. The lower cutting edge makes an acute angle with the horizontal lower cutter *c* (Fig. 86) carried by the fixed foundation. Across the front of the machine, and working in brass bushed bearings, is a steel shaft *d*, upon which are forged two eccentrics, connected by powerful straps and links *e* with the top of the slide, which thus ascends and descends as the shaft revolves. At one end of the machine is an engine with a heavy fly-wheel *f*, and the power is transmitted between the engine shaft and the eccentric shaft *d* through heavy spur or helical gearing, as shown. The slide or apron B is fitted with a stop motion worked by the handle *y* so as to prevent the descent of the slide, whilst a heavy plate is being moved forward and properly set after the last cut. Such a machine can shear through cold iron plates 1½ in. thick ; the slide is from 7 ft. to 11 ft. long, and the inner faces of the two standards are from 5 ft. to 9 ft. apart.

Guillotine shears of this type, but very narrow across the face—that is, between the sides of the machine—are used for cutting up hot steel ingots or blooms of from 3 in. to 10 in. square, into the lengths required for rolling into bars, etc.

Reheating Furnaces.—The furnaces are known as heating or reheating furnaces. They are of several kinds : (1) open fire, as used in conjunction with the finery ; (2) the hollow fire, as employed in South Wales for reheating the piles or stamps ; (3) the reverberatory furnace or mill furnace fired with coal as usually constructed for mill purposes for reheating iron or steel for the hammers or rolls ; (4) gas fired furnaces.

The forge reverberatory, or balling furnace, is generally arranged to burn raw coal or other solid fuels upon its own grate-bars ; whilst the reheating furnaces for the mills and forging hammers are frequently replaced by furnaces burning gaseous fuel.

The reheating, mill, or balling furnace, adapted to the consumption of raw fuel direct upon its own grate, resembles externally an ordinary puddling furnace. It is supported externally (*see* Fig. 87) by cast-iron plates and buck-staves *a* secured from side to side and from end to end by wrought-iron tie-rods passing over the top and secured to the plates by nuts on the screwed ends of the tie-rods. The balling

furnace has a smaller area of grate-bars than the puddling
furnace in proportion to the area of its bed ; the chimney *b*
is also a little higher. The furnace bottom is formed of
sand, oxide of iron, fire clay, or basic slag, on the top of a
fire-brick lining. This type of furnace is employed more
particularly in iron works for raising to a welding heat
the piles of puddled bar or the higher grades of malleable-iron,
previous to the rewelding of the same under the hammer, or
in the mill rolls.

Balling furnaces as used in the South Wales forges have
the hearth bottom made of cast-iron plates fixed about 14 in.
below the working door, and upon this is laid a course of
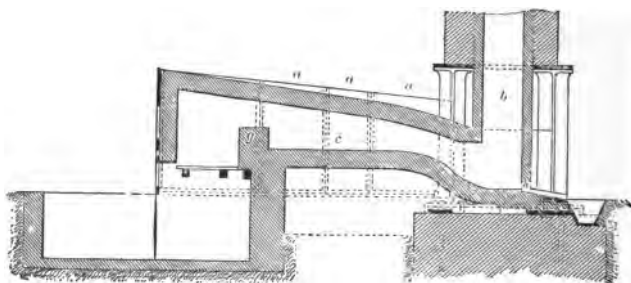
Fig. 87.—Reheating or Balling Furnace, Sectional Elevation.

fire-bricks upon which the working bottom is made by well
ramming in sand in a moist state. The bottom or bed *c*
slopes uniformly from the working door *d* (Fig. 87) to the
back of the hearth, as also from the fire-bridge *g* to the stack
b. The fire-bridge is built about 9 in. wide, and reaches to
within about 14 in. of the roof, and the chimney or flue-end
of the hearth is rounded off, and slopes, as shown (Fig. 87),
towards the bottom of the stack. The cinder from the hearth
thus flows along this flue to the tap-hole *h* at the base of the
stack, and the tap-hole is prevented from closing up by the
cooling and solidification of the slag or cinder within it by
keeping a small fire constantly burning in front of it. The
stoking-hole *k* is closed or stopped after firing by introducing
lumps of coal into the opening, and then throwing a shovelful
of coal slack over them just as is done with the puddling

furnace, whilst the draught is maintained and regulated to the requirements of the furnace by a stack, upon the top of which is a damper suspended from one end of a lever, from the other end of which hangs a rod reaching to the floor level. The height, as given above, of the roof from the bed of the furnace is adapted to the production of merchant iron of ordinary sizes, but for the heating of large slabs or forgings the roof may be raised, and the size of the doors increased considerably. In some furnaces, also, the cast-iron bed-plates are not introduced, in which case the sand bottom is prepared by ramming sand into a bottom of rubble masonry.

Gas furnaces are very largely used for reheating. They are usually of what is called the Siemens new type, in which there are only two regenerators—those for air, part of the products of combustion being sent through the gas producer, which is attached to the furnace. The gas enters and the products of combustion are drawn off at the same side. These and the other types of gas furnace will be fully described in the companion volume on " Steel."

The workman, or " baller," introduces the charges of piles into the balling furnace with the assistance of a heavy bar called a " peeler." The flattened end of the peeler rests during the time of charging upon the sill of the furnace door, where the smaller piles are placed upon it ; in dealing with heavier packets the peeler, with the pile upon it, is carried upon a bogie, which delivers it at the height of the furnace door. The peeler with its pile is pushed into the furnace, and the peeler is withdrawn, leaving the pile standing across the furnace parallel with the fire-bridge. For making merchant bars, four such piles are inserted into the furnace at one charging, care being taken not to disturb the arrangement of the bars. The charge is called a " heat," and instead of four piles making up the heat, sixteen or eighteen smaller piles are frequently introduced in one heat. When the charging is completed, the door is lowered into position, and a shovelful of coal is thrown around it to prevent the admission of air. The temperature of the furnace is then raised by cleaning the grate-bars, adding more fuel through the stoking door, re-stopping the latter with coal, and then raising the chimney damper. In this manner large piles will attain to a welding heat in about one hour, and small

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ones in thirty minutes ; they are withdrawn from the furnace
with tongs and drawn forward on to a bogie in front of the
door, which is run rapidly to the rolls, through which the
dripping pile is at once passed. When all the piles have been
withdrawn, the furnace bottom is usually slightly repaired
by introducing a little sand, and then all is ready for the
introduction of another heat. The withdrawal of the charge
and repair of the bottom usually occupy from fifteen to
twenty minutes.

During reheating, piles or ingots are moved about slightly
to facilitate more rapid and uniform heating over the whole
surface of the mass. As the mass approaches a welding
heat the iron rapidly oxidises and scales ; the scale falls
to the bottom of the furnace, where it combines with the
silica or sand of the bottom with the production of a readily
fusible slag or cinder, which flows away freely to the bottom
of the stack, subsequently escaping through the tap-hole.
The flue-cinder, or mill furnace slag, thus produced is
essentially a ferrous silicate, containing from 50 per cent.
to 60 per cent. of ferrous oxide, representing from 40 per
cent. to 45 per cent. of metallic iron, the other constituents
of the cinder being about 30 per cent of silica, with small
percentages of ferric oxide, manganous oxide, alumina, lime,
magnesia, sulphur, and phosphoric anhydride.

The consumption of coal in the production of No. 2 mer-
chant iron from the ore, including that consumed in the
calcination and smelting of the ore, the puddling of the pig-
iron, and the reheating for rolling into No 2 quality of iron,
is, roughly, about four times the weight of the bars produced ;
and there is an additional consumption of from 9 cwts. to
10 cwts. of coal per ton for each additional piling and reheating
necessary for the production of each higher grade of merchant-
able iron ; so that to make treble-best iron nearly 6 tons of
coal are consumed per ton of bars.

The yield of merchantable iron per ton of pig-iron treated
differs with the locality, the quality of the pig, the skill of
the workman, and the quality of iron produced, or the number
of separate pilings and reheatings to which it has been sub-
mitted ; but the average loss in the Staffordshire district
is about 25 per cent., and in South Wales it is somewhat
greater. Thus the loss in the Dudley district of Staffordshire

between the pig-iron treated and the puddled bars produced is about 10 per cent. or, more accurately, 24 cwts. of pig-iron usually yield 22 cwts. of puddled bars, while 22½ cwts. of the latter are required to produce a ton of merchant bar.

In the gas furnace the temperature is more under control, and there is a greater purity of flame upon the hearth than is possible in furnaces consuming raw coal upon the ordinary grate-bars. Further, an oxidising, neutral, or reducing atmosphere can be maintained in the heating chamber of the furnace according as more or less atmospheric air is admitted for the combustion of the producer gases, and the loss of metal from oxidation is thereby diminished. This economy in the reheating of 1¼-in. iron billets for the production of iron wire has amounted to about 5 per cent. In the gas reheating furnace the loss from oxidation does not exceed 2·5 per cent. of the metal charged, but with the ordinary coal furnace the loss is nearly 7 per cent. With steel, however, the direct economy is less, since the temperatures employed are lower and the oxidation and waste are therefore less active, whether coal or gas furnaces be employed. There is a total absence of smoke in working the gas furnace.

The use of the gas-producer instead of the ordinary grate permits of the consumption of inferior classes of fuel, such as coal slack, anthracite culm, and every variety of bituminous or semi-bituminous coals, lignites, peat, air-dried wood, etc. The gas-producer means a saving in the fuel consumption, and a more uniform heat. The contact of the fuel with the highly heated lining of the furnace is prevented, and therefore less repairs and longer campaigns are possible.

CHAPTER XX.

USEFUL TABLES, ETC.

TABLE OF ATOMIC WEIGHTS.

Element.		O = 16	Approx.	Element.		O = 16	Approx.
Aluminium	Al	27·1	27	Manganese	Mn	55·0	55
Antimony	Sb	120·2	120	Mercury	Hg	200·0	200
Arsenic	As	75·0	75	Molybdenum	Mo	96·0	96
Barium	Ba	137·4	137	Nickel	Ni	58·7	58½
Bismuth	Bi	208·5	208½	Nitrogen	N	14·04	14
Bromine	Br	79·96	80	Phosphorus	P	31·0	31
Cadmium	Cd	112·4	112	Platinum	Pt	194·8	194½
Calcium	Ca	40·1	40	Potassium	K	39·15	39
Carbon	C	12·0	12	Silicon	Si	28·4	28
Chlorine	Cl	35·45	35½	Silver	Ag	107·93	108
Chromium	Cr	52·1	52	Sodium	Na	23·05	23
Cobalt	Co	59·0	59	Strontium	Sr	87·6	87½
Copper	Cu	63·6	63½	Sulphur	S	32·06	32
Fluorine	F	19·0	19	Tin	Sn	119·0	119
Gold	Au	197·2	197	Titanium	Ti	48·1	48
Hydrogen	H	1·008	1	Tungsten	W	184·0	184
Iodine	I	126·85	126½	Uranium	U	238·5	238½
Iron	Fe	55·9	56	Vanadium	V	51·2	51
Lead	Pb	206·9	207	Zinc	Zn	65·4	65
Magnesium	Mg	24·36	24				

For all metallurgical calculations only the approximate atomic weights need be taken.

Problem I.—From the formula of a substance to find its molecular weight and percentage composition.

Solution.—1. Write down the formula. 2. Multiply the atomic weights by the number of atoms present. 3. Add the resulting numbers. 4. From this molecular weight find the proportion of each element in 100 parts.

Example.—Find the percentage composition of ferrous carbonate. Formula is $FeCO_3$.·. $Fe = 56 \times 1 = 56$.·. $\% = 56 \times 100 \div 116 = 48\cdot28$
$C = 12 \times 1 = 12$.·. $\% = 12 \times 100 \div 116 = 10\cdot37$
$O_3 = 16 \times 3 = 48$.·. $\% = 48 \times 100 \div 116 = 41\cdot35$

.·. Molecular weight $= 116$. $\overline{100\cdot00}$

Problem II.—From the percentage composition of a substance find its empirical formula.

Solution.—1. Divide the percentage of each element by its atomic weight. 2. Divide each quotient by the lowest number. 3. Allocate the factors.

Example.—Find the formula of a substance containing the following percentages :

| | At. wt. | | Ratio. |
Sulphur (S) $= 22\cdot53 \div 32 = 0\cdot704 = \cdot704 \times 1 = 1$
Sodium (Na) $= 32\cdot39 \div 23 = 1\cdot408 = \cdot704 \times 2 = 2$
Oxygen (O) $= 45\cdot06 \div 16 = 2\cdot817 = \cdot704 \times 4 = 4$
.·. Formula is Na_2SO_4.

Problem III.—Find the weight of a substance formed from a given weight of a known substance.

Solution.—1. Write down the equation representing the reaction. 2. Write the weights of the substances under the formula. 3. Calculate by simple proportion.

Example.—Find what weight of tri-manganese tetroxide will be formed on calcining one ton of manganese carbonate ; also the loss per cent., and hence the percentage increase of manganese.

Equation : $3 MnCO_3 + O = Mn_3O_4 + 3 CO_2$

Weights : $3 (55 + 12 + 48)$ parts yield $(55 \times 3 + 16 \times 4)$ and lose $3 (12 + 16 \times 2)$ on heating.

Simplifying : 345 parts yield 229 parts and lose 116 parts on heating.

Proportionately : 2,240 lbs. form $229 \times 2,240 \div 345 = 1,493$ lbs. = 13 cwts.

Loss per 100 parts $= 116 \times 100 \div 345 = 33\cdot623$.

Percentage of manganese $229 \times 100 \div 345 = 66\cdot377$.

The percentage of manganese increases from $165 \times 100 \div 345$ in the carbonate to $165 \times 100 \div 229$ in the oxide; *i.e.* from 47·826 to 72·052 on calcining.

Hence percentage increase of manganese $= 229 \times 100 \div 345 = 66·377$ %. From this the factor for Mn_3O_4 from $MnCO_3$ is got, *viz.* ·66 (approximately).

Some Useful Factors.

Given Unit Weight of	To find the Amount of Present.	Proportion.	Factor.	To find Amount of Obtainable.	Proportion.	Factor.
$FeCO_3$	Fe	$56 \div 116 =$	·4828	FeO	$72 \div 116 =$	0·6207
FeS_2	Fe	$56 \div 120 =$	·4667	Fe_2O_3	$160 \div 240 =$	0·6667
Fe_3O_4	Fe	$168 \div 232 =$	·7241	FeO	$216 \div 232 =$	0·9310
Fe_2O_3	Fe	$112 \div 160 =$	·7000	FeO	$144 \div 160 =$	0·9000
FeO	Fe	$56 \div 72 =$	·7778	Fe_2O_3	$160 \div 144 =$	1·1111
$CaCO_3$	Ca	$40 \div 100 =$	·4000	CaO	$56 \div 100 =$	0·5600
CaS	Ca	$40 \div 72 =$	·5556	CaO	$56 \div 72 =$	0·7778
$MnCO_3$	Mn	$55 \div 115 =$	·4786	Mn_3O_4	$229 \div 345 =$	0·6638
MnO	Mn	$55 \div 71 =$	·7747	Mn_3O_4	$229 \div 213 =$	1·0751
$MgCO_3$	Mg	$24 \div 84 =$	·2857	MgO	$40 \div 84 =$	0·4762
P_2O_5	P	$62 \div 142 =$	·4366			
SO_3	S	$32 \div 80 =$	·4000	SO_2	$64 \div 80 =$	0·8000
SO_2	S	$32 \div 64 =$	·5000	SO_3	$80 \div 64 =$	1·2500

Although the fourth decimal place is indicated, only the third significant figure need be taken as an approximation.

TABLE OF THERMAL AND PHYSICAL CONSTANTS USEFUL IN CALCULATIONS ON COMBUSTION.

| | Calorific Power of Carbon Burning to Gas. C.U. | Density of Gas. | Weight of one cub. ft. in lbs. | Weight of one litre in grammes. | Specific Heat. | Calorific Power of Gas, C.U. | Factors for Combustion of Unit Weight of Gas. | | Factors for Combustion of Unit Volume of Gas. | | Factors for Volume of Products of Combustion from Unit Volume of Gas. | |
							Oxygen.	Air.	Oxygen.	Air.	Steam.	CO_2.
CO_2	8,080	22	·1234	1·9712	·2169	...	...	...	...	...	...	...
CO	2,400	14	·0784	1·2544	·2450	2,400	·572	2·49	0·5	2·38	...	1
CH_4	1,543	8	·0447	0·7168	·5929	12,000	4·00	17·4	2·0	9·52	2	1
C_2H_4	663	14	·0784	1·2544	·4040	10,400	3·43	14·9	3·0	14·28	2	2
C_2H_2	1,852 –	13	·0734	1·1648	(?)	11,500	2·86	12·4	2·5	11·9	2	2
H	...	1	·0056	0·0896	3·409	29,300	8	34·8	0·5	2·38	1	...
O	...	16	·0893	1·4336	·2175							
Steam (H_2O)	...	9	·0502	0·8064	·4805							
N	...	14	·0784	1·2544	·2438							
Air (N + O)	...	14·438	·0809	1·2936	·2375							

C.U. = Centigrade Units.

C.U. × $\frac{9}{5}$ = B.Th.U. (British Thermal Units).

Volume of a gas increases by $\frac{1}{273}$ = (·003663) of itself for each one degree centigrade (1°C) rise of temperature.

Air contains	By Weight.	By Volume.
N	77 %	79 %
O	23 %	21 %

The caloric power of a fuel is the number of heat units evolved by the complete combustion of one pound (1 lb.) of it.

The heat unit is the amount of heat required to raise 1 lb. of water 1 degree $\left(\begin{array}{l}\text{B.Th.U. 1 degree Fahrenheit} \\ \text{C.U. 1 degree Centigrade}\end{array}\right)$.

The specific heat of a substance is the number of heat units required to raise the temperature of 1 lb. of it one degree.

The density of a gas is half its molecular weight.

USEFUL FACTORS IN CALCULATING BLAST FURNACE CHARGES BASED ON FORMING MONOSILICATES 2 RO, SiO_2.

To find	*Required to Combine with one part of*	*To Form Mono-silicate.*	*Proportion.*	*Factor.*	*Reciprocal, i.e. Factor for Silica for 1 Part of Base.*	*Lime Equivalent.*
Alumina	Silica	$2\,Al_2O_3,\ 3\,SiO_2$	$180 \div 204 =$	·8824	1·133	$\dfrac{56 \times 3}{102} = 1\text{·}647$
Lime	Silica	$2\,CaO,\ SiO_2$	$60 \div 112 =$	·5358	1·866	$\dfrac{56}{56} = 1\text{·}000$
Magnesia	Silica	$2\,MgO,\ SiO_2$	$60 \div 80\ =$	·7500	1·333	$\dfrac{56}{40} = 1\text{·}400$
Manganous Oxide	Silica	$2\,MnO,\ SiO_2$	$60 \div 142 =$	·4226	2·367	$\dfrac{56}{71} = 0\text{·}7886$
Iron	Silica	$2\,FeO,\ SiO_2$	$60 \div 112 =$	·5358	1·866	$\dfrac{56}{56} = 1\text{·}000$
Ferrous Oxide	Silica	$2\,FeO,\ SiO_2$	$60 \div 144 =$	·4167	2·400	$\dfrac{56}{72} = 0\text{·}7778$
Lime	Sulphur	Ca S	$56 \div 32\ =$	1.75	...	...

One half of the manganese in the ore passes into the iron along with all the phosphorus.

The pig-iron formed is usually assumed to contain 92 % of metallic iron, with 2·5 % of silicon.

Practically all the sulphur in the ore passes into the slag as calcium sulphide (CaS).

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STEEL

ITS VARIETIES, PROPERTIES, AND MANUFACTURE

WITH NUMEROUS ENGRAVINGS AND DIAGRAMS

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MCMVII

PREFACE.

STEEL: ITS VARIETIES, PROPERTIES, AND MANUFACTURE, con-
tains, in a form convenient for everyday use, a comprehensive
treatise on the subject. The contents of this manual are based
on the highly esteemed book written by the late William Henry
Greenwood.

Without omitting any essential part of the original work
the matter has been revised, entirely rewritten, and brought up
to date by Mr. A. Humboldt Sexton, F.I.C., F.C.S., Professor of
Metallurgy in the Glasgow Technical College. Needless to say
many and important changes have taken place since the
previous edition was published, and whilst the new processes
and appliances have been incorporated, some of the older
methods which are still of interest have been revised and
retained. In this manner the manual has been made valuable,
not only to the student but to all who are interested in steel.

Readers who may desire additional information respecting
special details of the matters dealt with in this book, or in-
structions on any kindred subjects, should address a question
to the Editor of WORK, La Belle Sauvage, E.C., so that it
may be answered in the columns of that journal.

<div align="right">P. N. HASLUCK.</div>

La Belle Sauvage, London,
August, 1907.

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STEEL: ITS VARIETIES, PROPERTIES, AND MANUFACTURE.

CHAPTER I.

Steel. The term steel as now used covers a large number of materials, varying so much in composition and properties that it is impossible to frame a definition which will include all varieties and exclude all else. It may be sufficient here to say that all commercial varieties of iron, except malleable iron and cast iron (including under the latter term such alloys as ferromanganese and ferrochrome), may be called steel. Steels may be divided into two main groups : (1) those which depend for their useful properties on the amount of carbon present, other foreign constituents being always in small proportion, and (2) those which depend for their useful properties on some other element, usually a metal, and almost always in conjunction with carbon. The former may be called carbon steels, the latter alloy steels.

Carbon Steels.—Carbon steels are essentially iron containing carbon, usually with only small proportions of other foreign elements, such as are present not being intentionally added but being accidental constituents. The nearer a carbon steel approaches to an alloy and iron the purer it may be said to be.

Iron can combine with carbon in all proportions up to about 4·5 per cent., and up to 2·2 per cent. the metal may be called steel, whilst above that it is cast iron.

Steel is often classified according to the amount of carbon present, the following being a convenient classification for practical purposes :—

Mild or structural steel　Carbon up to ·5%·$\begin{cases} \text{Dead mild C. under ·1.} \\ \text{Mild} \quad\quad \text{C. ·1 to ·3.} \\ \text{Medium} \quad\text{C. ·3 to ·5.} \end{cases}$

Hard or tool steel, carbon over ·5 per cent.

Alloy Steels.—Alloy steels are classified according to the metal alloyed with the iron, as, for example, nickel steel, chrome steel, manganese steel, etc. These will be considered in Chapter XV.

Properties·of Steel.—Steel is selected for various purposes according to its properties. The principal properties which are taken into account are tenacity or tensile strength, ductility, elastic limit, modulus of elasticity, and hardness.

Tenacity is the strength with which the metal resists being pulled asunder. It is measured by the weight, in either pounds or tons, required to pull asunder a bar, and if the bar be of 1 sq. in. section, the weight is called the tensile strength.

Modulus of Elasticity.—If a tensile stress be applied to a bar of steel the bar is slightly elongated, if the stretching weight be doubled, the elongation is doubled, and so on, the stretching or strain being proportional to the stretching weight or stress. The weight which would be required to double the length of a bar of 1 sq. in. section, provided the elasticity remained perfect, is called the "Modulus of elasticity," or Young's modulus. No metal will stand stretching to anything like double its length without fracture, but the modulus can be calculated from the extension produced by a known weight, on the assumption that the strain is proportional to the stress. Suppose you instance the elongation produced on a bar 10 in. long by a stress of 5 tons to the 0·00385 in., then, if a stress of 5 tons produces an elongation of 0·00385 in., the stress which would be required to produce an elongation of 10 in., *i.e.* to double the length of the bar, would be $\dfrac{5 \times 10}{·00385} = \dfrac{50}{·00385} = 12{,}987$ or, say, 13,000 tons. It is obvious that the actual measurement to be made is so small that great accuracy cannot be expected in the results.

Limit of Elasticity.—As a moderate stress is applied the bar elongates, and when the stress is removed the bar returns to its original length, and, as already remarked,

the strain is proportional to the stress. As the stretching weight is increased a point is at length reached when the bar no longer returns to its original length, but remains slightly longer, having taken a permanent set. If the stress be increased the bar continues to stretch, but the stretching is no longer proportional to the stretching weight. This is the limit of elasticity.

Ductility.—This is measured by the extent to which a bar elongates before actual fracture. It is always stated as a percentage of the original length of the bar.

Compression Strength.—When a cube of 1 in. side is compressed with a sufficiently great pressure it may fracture. The pressure required to produce fracture in tons or pounds is the compressive strength of the material. A ductile substance, such as mild steel, cannot be said to have any definite compressive strength, because as the stress is increased sufficiently the metal flows, so that whilst the thickness diminishes the area increases till it can support the stress.

Hardness.—This is a difficult property to estimate and to state. It is usually measured either by the weight which is required on a diamond or hard steel point to produce a distinct scratch, or by the amount of indentation produced by a heavily weighted point or knife edge. In either case the results depend so much on the conditions of the experiment that it is impossible to draw up a scale of hardness that will be of any value unless the conditions of the experiment are exactly defined.

Testing Steel.—For commercial purposes certain tests are usually applied to steel. The tests must be sufficiently accurate and exhaustive to determine with certainty the quality of the steel, and at the same time must be so simple that a large number of tests can be made in a short time.

The Test Piece.—A test piece, which may be either circular or rectangular in section, is made by turning or machining, so that there is a middle portion of perfectly uniform section and the sides being exactly parallel, 8 or 10 in. long, with wider portions at each end, the wide and narrow portions being curved one into the other so that there is no sharp line of demarcation between them, and two dots or other marks, the distance between

which can be accurately measured, are made on the
narrow portion of the test pieces.

The Testing.—The test piece, Figs. 1 and 2, having been
accurately measured, is fixed in a testing machine, by which
a stress can be slowly and continuously applied until the
piece breaks. It is essential that there should be no
jerking or sudden application of the stress. The test
piece is firmly fixed in the grips of the machine, and as the
stress is applied the bar begins to elongate, the elongation
being uniform over the whole length of the piece. As the
stress is increased the limit of elasticity is reached, and
the bar takes a permanent set; this point can only be
detected by a series of accurate measurements, and there-
fore usually in practice no notice is taken of it. As the
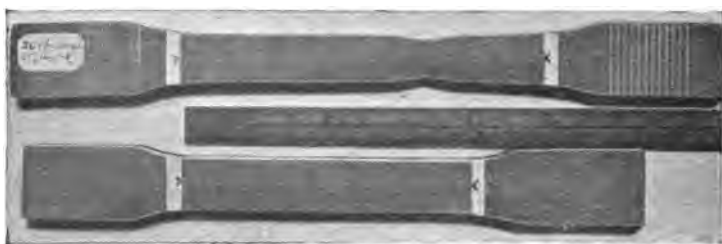
Figs. 1 and 2.—Test Piece, before and after Fracture.

stress is still increased the bar suddenly elongates, the
elongation being so great that a drop of the lever of the
testing machine can be noticed. This is called the yield
point, but it is often confounded with the elastic limit,
and when the elastic limit is specified commercially it is
usually the yield point that is taken. The stress at the
yield point is always greater than the elastic limit.

As the stress is still further increased the bar still
stretches, and soon a point is reached when local contrac-
tion begins, and the bar does not stretch evenly over its
whole length, but only over a small portion, in which frac-
ture will ultimately take place and which becomes rapidly
smaller. This point is called the fluid point. It is the
point at which the metal has the maximum strength, as is
shown by the fact that though the bar rapidly decreases in

area it does not break. At the fluid point the molecules are free to flow over one another, as in the case of a fluid. As the stress is continued the bar ultimately breaks. The softer and better the steel the longer will the period of flow continue.

The points determined by the test are :—

(1.) The ultimate breaking strength (stress). From this the tensile strength, measured on 1 sq. in. of original section, is easily calculated.

(2.) The yield point, which is usually about one half of the ultimate breaking strength.

(3.) The modulus of elasticity.

(4.) The extension before fracture. The broken surfaces of the test piece are put together and the distance between the punch marks, which was originally 8 or 10 inches, is measured. The extension is then calculated to a percentage of the initial distance between the marks.

(5.) The area of the bar at the point of fracture can be measured, and this gives the contraction of area which is sometimes asked for.

The fracture should be concave or cup-shaped on the one half and convex on the other, and should show a uniform white granular surface. The fracture should take place near the middle of the test piece. Should it be very near one end the test is rejected.

Other tests are used for special purposes, and the more important of these will be described in Chapter XVI.

Effect of Carbon on Iron.—In carbon steels, carbon is the essential constituent, and other elements may be considered as impurities, more or less objectionable, and whilst it is impossible to obtain a steel which contains nothing but carbon and iron, the nearer this condition is approached the better.

Pure iron is very soft and ductile, and has a tensile strength of about 17 tons. The figure cannot be obtained with absolute certainty, because it is impossible to prepare and test perfectly pure iron, but it has been judged from the strength of steels containing only a small percentage of carbon.

The effect of carbon, as indeed of most other elements likely to occur in steel, is to increase the tensile strength

of the metal and at the same time to reduce the ductility, as measured by extension of the test piece before fracture, but the two are not proportional. As strength is usually required with as little decrease of ductility as possible, carbon is the best hardening agent, because it gives the increase of strength with less reduction of ductility than most of the other hardening agents, and carbon steels have some valuable properties which are not produced by the addition of other elements. No doubt the selection of carbon as the hardening agent was in the first instance accidental, and was due to the fact that the iron, was reduced in contact with charcoal, under such conditions that carbon could be readily taken up.

TABLE SHOWING AVERAGE VALUES OF BREAKING STRAIN IN TONS CORRESPONDING TO PERCENTAGE OF CARBON IN MILD STEEL.

Carbon. Per cent.	*T.S.* Tons.	*Carbon.* Per cent.	*T.S.* Tons.
·12 ...	25	·29 ...	$37\frac{1}{2}$
·13 ...	26	·30 ...	$37\frac{1}{2}$
·14 ...	27	·31 ...	$37\frac{1}{2}$
·15 ...	28	·32 ...	38
·16 ...	29	·33 ...	38
·17 ...	30	·34 ...	$38\frac{1}{2}$
·18 ...	31	·35 ...	$38\frac{1}{2}$
·19 ...	32	·36 ...	39
·20 ...	33	·37 ...	39
·21 ...	$33\frac{1}{2}$	·38 ...	39
·22 ...	34	·39 ...	$39\frac{1}{2}$
·23 ...	$34\frac{1}{2}$	·40 ...	$39\frac{1}{2}$
·24 ...	$35\frac{1}{2}$	·41 ...	40
·25 ...	$36\frac{1}{2}$	·42 ...	40
·26 ...	37	·43 ...	$40\frac{1}{2}$
·27 ...	37	·44 ...	$40\frac{1}{2}$
·28 ...	37	·45 ...	41

Notes.—(1) From ·12 to ·20 per cent. carbon the relation holds, viz.: (Carbon per cent. × 100) + 13 = T.S.

(2) Phosphorus below ·03 per cent. lowers T.S. about $1\frac{1}{2}$ tons.

(3) Silicon from ·2 to ·3 per cent. raises T.S. about 1 ton.

The addition of 0·1 per cent. of carbon increases the tensile strength of iron to about 22 tons, and, as the percentage of carbon is increased, the tensile strength rises till 100 tons or thereabouts may be reached. It is impossible to give any regular law of increase, since the properties depend not only on the percentage of carbon present but on the condition in which it exists as determined by the treatment which the metal has undergone, especially by the rate of cooling, steels suddenly cooled (*e.g.* quenched in water) having a greater tensile strength and being harder than those which are cooled slowly. With very low carbon steels the influence of the rate of cooling is small, but when the carbon reaches about ·5 per cent. it is quite distinct, and with 1 per cent. of carbon or more the metal, on quenching, becomes very hard and brittle. Annealed steels are those which have been heated to redness and allowed to cool very slowly; quenched steels are those which have been heated to redness and quenched in water; whilst normal steels, which have been allowed to cool slowly in air, occupy an intermediate position. The table on page 14 gives approximately the relation existing between carbon content and strength in mild steels.

Professor Arnold has found that for annealed steel the tensile strength increases with the percentage of carbon from about 19 tons with ·08 per cent. of carbon, till a maximum of about 36 tons is reached, when there is about ·9 per cent. of carbon present, after which the strength falls off, till when its carbon reaches 1·47 per cent. it is about 22 tons. With steel in the normal condition, which had been heated to 1,000° C., and allowed to cool in air, the tensile strength rose from 21 tons, with ·08 per cent. of carbon, to about 61 tons with 1·2 per cent. of carbon, after which it fell somewhat (see Figs. 3 and 4, pp. 16 and 17).

The ductility decreases as the carbon increases, but here again no definite rule can be given. Professor Arnold found, with the same samples of steel as he used for his tensile test experiments, that the extension of test pieces of steel which contained ·08 per cent. of carbon was 52 per cent., but that it fell continuously as the carbon was increased, until it reached a minimum of about 6 per cent., when the steel contained ·89 of carbon. As the carbon was

further increased the extension also increased, till, with
carbon 1·47 per cent., it reached nearly 20 per cent. With
the normal steel a minimum was not reached, but the
fall continued till it was only about 2 per cent. with 1·47
per cent. of carbon.

The difference in the behaviour of the steel in the two
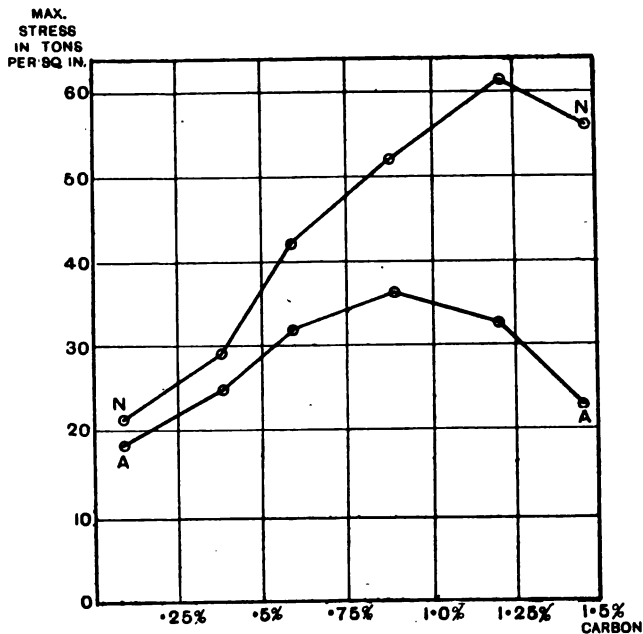
Fig. 3.—Influence of Carbon on Tenacity of Steels.
N = Normal.   **A** = Annealed.

conditions depends either on differences in the condition
of the carbon, or on differences in the condition of the iron
itself.

If a piece of pure, almost carbonless, iron be heated to
redness and then cooled suddenly by quenching in water,
it is not noticeably harder than if it had been allowed
to cool slowly. As the percentage of carbon is increased
the difference between the annealed and quenched samples
becomes more and more marked. With ·5 per cent. of

carbon it is sufficient to be easily detected by rough work-shop tests, and with 1·0 per cent. of carbon the quenched metal becomes very hard and brittle. The normal metal, being cooled neither very quickly nor very slowly, occupies an intermediate position. It is essential that the student should understand that the properties of a steel due to carbon depend not only on the amount of carbon present, but also on the way in which the metal has been treated.
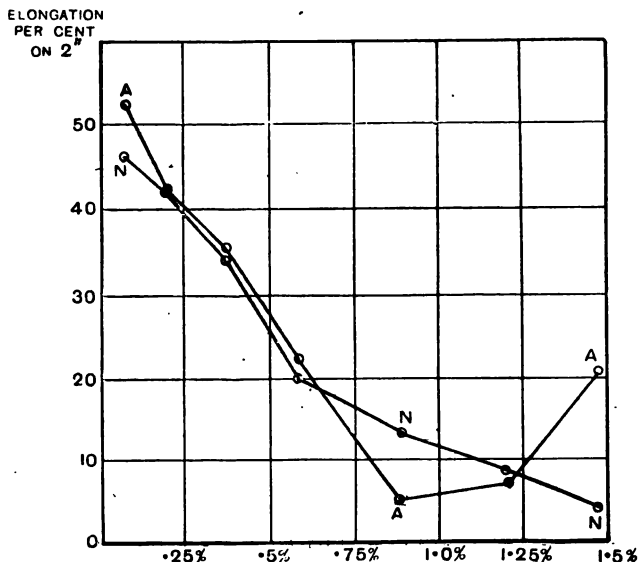
Fig. 4.—Influence of Carbon on Ductility of Steels.
N = Normal. **A** = Annealed.

The modulus of elasticity is about 13,000 tons, and does not vary much with variations in the percentage of carbon.

Owing to the great influence of variation in the percentage of carbon on the qualities of the metal, steel can be made suitable for very many purposes; it may be either very soft and tough, or hard and brittle, and the properties may be still more modified by suitable heat treatment, as by hardening and tempering, so that almost any property required for a special purpose may be

B

obtained, and a still greater range of properties is obtainable by the addition of other metals in the alloy steels.

The following table will give an idea of the varieties of steel made and the purpose for which each variety is used, the classification being based on the percentage of carbon. It must, of course, be understood that the figures are only examples and may be varied very considerably according to the properties required in the articles being made.

Carbon.	*Uses.*
·05 to ·07 per cent. ...	Wire rod.
·09 to ·12 „ ...	Wire rod. Tin bar for rolling into sheets for the manufacture of tin-plate.
·14 „ ...	Rivets.
·13 to ·18 „ ...	Boiler plates.
·15 to ·17 „ ...	Ship plates.
·17 to ·20 „ ...	Girders.
·23 to ·30 „ ...	Railway axles.
·30 to ·50 „ ...	Hard wire rod.
·30 to ·40 „ ...	Rails.
·45 to ·50 „ ...	Locomotive tyres.
·5 „ ...	Springs.
·75 „ ...	Dies.
·75 to 1·00 „ ...	Wood chisel sets and other tools.
1·00 to 1·25 „ ...	Turning tools, drills, etc.
1·25 to 1·50 „ ...	Files. Cutting tools requiring a keen edge, such as razors.
1·50 to 2·00 „ ...	Draw plates for wire drawing.

The influence of carbon on the magnetic properties of iron is of some little importance. Pure, soft iron becomes highly magnetic when it is brought into a magnetic field (its magnetic permeability is very high), but it has little power of retaining the magnetism when removed from the field (its retentivity is low). As the carbon is increased the retentivity increases and the permeability decreases. Arnold has found that the magnetic retentivity reaches a maximum when the carbon is ·89 per cent., and does not increase with increase of carbon beyond this

amount. Hardened steel retains its magnetism much more strongly than soft steel.

Influences of Other Constituents on the Properties of Steel.

Silicon.—Silicon is always present in steel in small quantity, and its influence has been very much discussed. In general it has much the same effect as carbon, tending to increase the tensile strength and diminish the ductility, but to a much less marked extent, 0·1 per cent. of silicon being roughly equal to ·02 per cent. of carbon in hardening power. Up to ·315 per cent. Turner found no increase in tensile strength or reduction in ductility, whilst with ·5 per cent. the increase in tensile strength was only 7 tons and the reduction of elongation 4 per cent. on a 10-in. test piece. When the carbon is low, silicon, even up to 1·5 per cent., does not destroy the ductility of the metal or its forge-ability at a red heat. Silicon in proportions in which it is likely to be present in steel, has therefore no injurious effect upon the metal. The presence of silicon tends to ensure castings free from blowholes, and, owing to its great affinity for oxygen, it probably decomposes any oxide of iron that may be present, and for this reason a little is sometimes intentionally added in the form of ferrosilicon or silicon-ferro-manganese.

Sulphur.—Sulphur in any proportion in which it is likely to be present in steel has no influence on the tenacity or ductility of the metal in the cold, but a very small proportion has a distinct influence on the ductility of the metal at a red heat, tending to make it red short, so that the ingots crack at the edges on rolling. The red shortness is noticeable with less than ·1 per cent. of sulphur, and ·06 per cent. is the maximum allowable in steel, which has to be worked hot. Even when there is no distinct red shortness visible during rolling, minute flaws may be produced which will be a cause of weakness and may subsequently determine fracture. Sulphur may be derived from the iron from which the steel is made, or it may in some cases be taken up, to a small extent, from the gas or other fuel used. Sulphur is rarely present in any quantity in high carbon steel, mainly because the material from which it is made is free from sulphur, and none can be taken up during manufacture, and partly because carbon tends to expel sulphur.

Phosphorus.—This element is usually, and rightly, con-sidered to be the steel-maker's greatest enemy, not that it is in itself more injurious than sulphur, but that it is much more likely to be present in objectionable quantity.

Phosphorus up to, say, ·1 per cent. seems to have but little influence on the properties of the steel as deter-mined in the testing machine, provided the carbon is low, except that it may slightly increase the tensile strength; it, however, greatly increases the liability of the metal to fail under sudden shock, though even in this respect the results obtained by various experimenters have been very variable. It seems to raise the elastic limit, and in some cases elastic limit and ultimate breaking stress nearly coincide. Even a large percentage of phosphorus, say 1·0 per cent., does not prevent the metal being worked hot, but when cold it may be extremely brittle, owing, perhaps, at least partly, to the coarsely crystalline structure which is induced by the presence of phosphorus. The limit of phosphorus allowable in ordinary steels is ·05 to ·06 per cent., though Harbord states that for rails ·08 per cent. may be allowed. With steels high in carbon a very much smaller proportion of phosphorus is allowable, ·01 per cent. being about the maximum for the best results, the influence of phosphorus increasing with the percentage of carbon.

Manganese.—Manganese is almost invariably present in mild steel, owing to the addition of ferromanganese as a deoxidising agent in the process of manufacture. The tendency of manganese is to harden the metal and in-crease its brittleness and liability to fail under shock, it slightly increases its tensile strength and diminishes ductility, and it seems to neutralise to some extent the red shortness due to sulphur. The limit allow-able varies with the purpose for which the metal is to be used, and in general it should not exceed about ·06 per cent.; 1 per cent. is, however, frequently present, and Howe mentions good rails containing 1·5 per cent. As manganese has a great affinity for oxygen and its oxide is not soluble in molten iron, it removes any oxides of iron that may be present in solution.

Arsenic.—Arsenic is rarely present in steel except in very minute quantity. Up to about ·1 per cent. it seems

to have little influence on the quality of the metal, but above that it produces red shortness, and it also interferes with the welding power, steel with over ·5 per cent. being unweldable. It lowers the elastic limit and decreases the elongation before fracture.

Copper.—The influence of copper does not seem to be very marked. It slightly increases the tensile strength and does not seem to produce red shortness.

Other elements are never present in large enough quantities to be of any importance.

Processes for the Manufacture of Steel.

A large number of processes have been used at various times for the preparation of steel.

(1.) Iron may be reduced from its ores in presence of carbon under such conditions that enough carbon is taken up to produce steel. Such processes may be called direct processes. They are now very little used, as they are costly, the steel is produced in small quantities, and is of uncertain composition.

(2.) Malleable iron, which is nearly carbon free, may be taken as the starting point, and carbon may be added to it by melting in contact with charcoal, in crucibles, as in the Indian process of making Wootz steel, or by heating with charcoal to welding temperature in larger vessels, as in the cementation process which is still largely used in Sheffield.

(3.) Pig iron, containing, as pig iron always does, a large quantity of carbon and silicon, may be taken as the starting point. It may be either (1) partially decarburised, the required amount of carbon being left in the metal as in the old process of puddling for steel and the Swedish Bessemer process; or (2) the carbon and silicon may be completely burnt out, and the required amount of carbon subsequently added in some convenient form, as in the Bessemer and open hearth steel processes.

In the following pages those processes which are now in use will be described, with only a brief reference to the minor processes, which are only of historical interest. The processes described will be—

(1.) The Bessemer Process :
    a. The ordinary or acid process.
    b. The basic process.
(2.) The Siemens or open hearth process :
    a. The acid process.
    b. The basic process.
(3.) The cementation process.
(4.) Puddling and minor processes.

CHAPTER II.

Principle.—When a stream of air is blown through molten pig iron, which always contains a large quantity of carbon and silicon, these elements, together with some of the iron, are rapidly oxidised, the carbon escaping in the form of gas, as carbon-dioxide or carbon-monoxide, and the silicon passing into the slag as silicate of iron.

Fig. 5.—Bessemer Converter.

The heat evolved by the oxidation is sufficient to keep the metal molten, even after all the carbon has been removed and the metal has therefore reached its least fusible condition. These facts were discovered by Bessemer about 1855, and are the basis of the process which is now known by his name. When the oxidation is finished, the metal

has absorbed some oxygen, and, if cast in that condition, would be brittle and useless. This is overcome by the addition of manganese in the form of ferro-manganese,
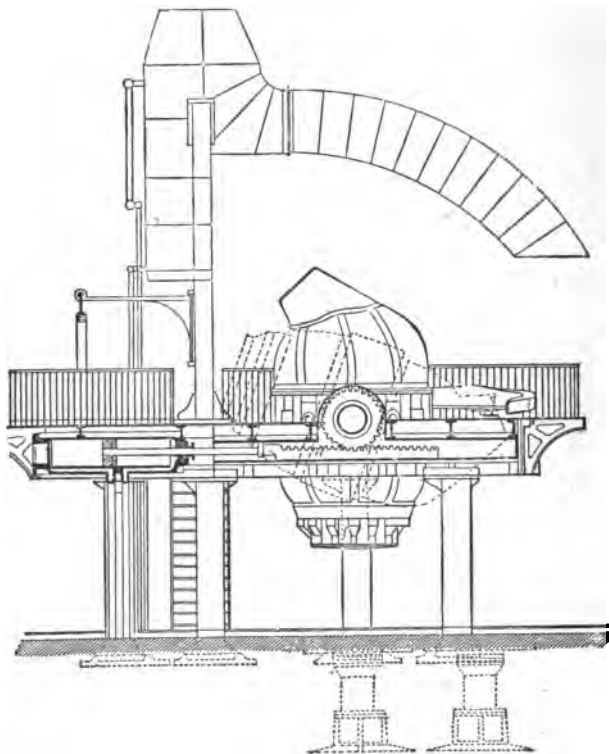
Fig. 6.—Bessemer Converter, showing Tilting Gear.

by which the oxygen is removed. The use of manganese was suggested by Robert Mushet in 1856.

The molten pig iron is run into a vessel of suitable form, and air is blown through it until oxidation is complete, which is indicated by the drop of the flame at

the mouth of the vessel. The ferro-manganese is then added, and the metal is poured into a ladle, and thence distributed to the moulds.

~ **The Plant.**—The form of plant now generally used for carrying out the process was devised by Bessemer. The essential parts are :—

(1.) The converter or vessel in which the oxidation takes place.

(2.) Apparatus for supplying the molten iron.

(3.) Apparatus for dealing with the steel.

The Converter.—This is the essential part of the plant. It is a vessel made of sheet steel, from $\frac{3}{4}$ in. to 1 in. thick, and having something of the form and dimensions shown in Figs. 5 and 6, which represent a 10-ton converter. The converter is made in three parts : the hood or top portion, the body or middle portion, and the bottom—and these are secured by catches so that they can be easily separated when necessary for relining. Round the body portion, which is usually cylindrical, is fixed a strong iron band— the " trunnion ring," to which are fixed the trunnions on which the converter rotates. The one trunnion is hollow and communicates with the blowing engines, and is so arranged that air can enter the converter whilst it is rotated through at least 90°. To the other trunnion is attached a toothed wheel working in a rack, operated by an hydraulic ram, by which the converter can be rotated through at least 200° (Fig. 7, Filling ; Fig. 8, Blowing ; and Fig. 9, Pouring Bessemer Converter). The body and hood are lined with very refractory siliceous material to a thickness of about 12 in. The bottom portion is closed at the bottom by an iron plate, in which there are a series of circular openings, through which the fire-clay tuyeres are put. Beneath this is a circular air-chest, the bottom of which is closed by an iron plate, held in place by keys, so that it can be very quickly removed when necessary, into which air is led by a pipe passing from the air trunnion down the side of the converter. The bottom lining is about 18 in. thick. The tuyeres (Fig. 10, Plan ; Fig. 11, Side Elevation ; Fig. 12, Section on A B, Fig. 10, are made of fire-clay, slightly conical and extended at the lower ends, and are perforated by from five to twelve holes, each from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. in diameter. They are pushed in through

the holes in the bottom plate and are held in‚ place by catches.
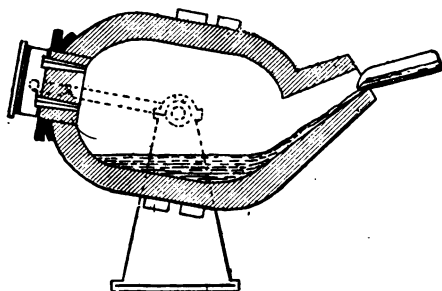
Fig. 7.
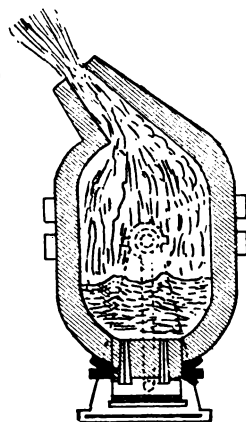
Fig. 8.
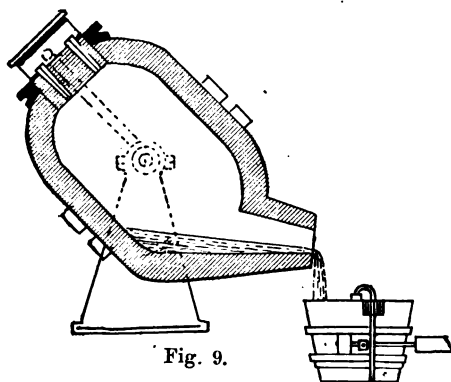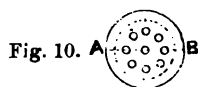
Fig. 10. A B
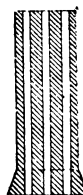
Fig. 11.   Fig. 12.

Fig. 7.—Filling Bessemer Converter.   Fig. 8.—Blowing Bessemer Converter.   Fig. 9.—Pouring Bessemer Converter.   Fig. 10.— Plan of Bessemer Tuyere.   Fig. 11.—Side Elevation of Bessemer Tuyere.   Fig. 12.—Bessemer Tuyere.   Section on A B (Fig. 10).

Lining the Converter.—The converter is lined with some very refractory lining.   In Britain the material used

is ganister, a slightly argillaceous sandstone, occurring in
the neighbourhood of Sheffield, containing just enough
clay to enable it to bind. In the United States an arti-
ficial ganister, called monolithic, made by mixing crushed
quartz and crushed firebrick with clay, is often used.
The hood and bottom are removed to the shop for relining,
but the body is lined in position.

The usual method of putting a lining into the body
is to fix a wooden core of the form which the interior is
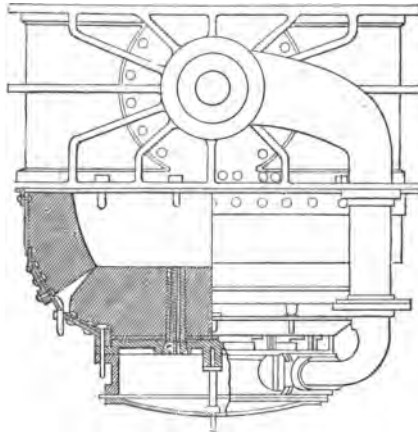
Fig. 13.—Bessemer Converter, showing Holley's Movable Bottom.

to be, supported on a temporary platform, inside it, and
then to ram the ganister or other material being used for
the lining, made plastic by mixing with water, round it.
Another method is to mix the ganister with water till it is
plastic, as in crucible making, then to cut this up into
lumps and press these into position by hand, the inside
being smoothed over with a wooden template.

The hood and the bottom are placed, open end up, on
the floor, and the lining is rammed in, in the case of the
bottom wooden dummies being put where the tuyeres are
to be. The bottom is thoroughly dried, either by heating
it in a stove or by putting a cover over it and burning

a jet of gas above it. When the bottom is dry the dummies are taken out, and the tuyeres, covered with a wash of fire-clay, are put in.

The joint between the hood and the body is not of much importance, but the joint between the body and the bottom must be sound or the molten metal would escape. To secure a sound joint several methods are used. One is to make the casing of the converter in such a way as to leave a space all round, and to make the linings so that they touch only on the inner edge, thus leaving a V-shaped ring which can be filled from outside (see Fig. 13). Another method is to spread a layer of moist ganister on the surface of contact of the body lining, and then, the body being inverted, to drop the bottom, also inverted, into position from above, its weight pressing on the ganister making a tight joint, or to lift the bottom into place from below and press it home by means of an hydraulic ram.

As the lining of the body takes twelve hours or more, this entails considerable loss of time, and to avoid this a type of converter has been introduced in America in which the body is independent of the trunnion band, so that the whole converter can be lifted away and carried to the repair shop and a new one put in place with little delay.

The Supply of Iron.—The pig iron must be supplied in a molten condition. It may be specially melted in a cupola or it may be supplied direct from the blast furnace, the former being the more usual way.

The cupolas were at one time usually placed on a platform in such a position that the metal could be tapped directly into the converter. For many reasons this position is inconvenient, and the cupolas are now usually placed at some distance from the converters, the metal being tapped into a ladle, which is brought by a locomotive, or other means, up an inclined plane to the converter level, and then, by tilting the ladle, is poured into the converter.

The cupolas were at one time placed on a plat-iron foundry, but must be of sufficient size to keep up a regular supply of iron. For an ordinary 10-ton plant, with two converters, that will be about 30 tons of iron per hour. When the metal is supplied direct it is tapped from the blast furnace into a metal mixer (see the companion
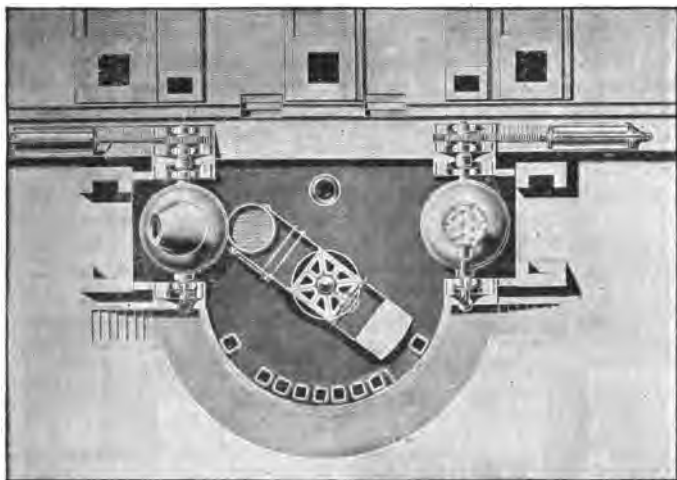
Fig. 14.—Plan of Bessemer Works.

Fig. 15.—Section of Bessemer Works.

volume, " Iron," p. 121, and thence is poured into the
ladles for conveyance to the converter.

The advantage of remelting is that the iron can be
selected, and thus a more uniform quality of supply can
be assured, but it entails not only the cost of remelting but
the cost of handling the pig at the blast furnace. The use
of direct metal is now becoming very general.

Arrangement of the Plant.—For economic working two
converters are always used. In the old or English type
of plant, as designed by Bessemer, these are placed as
shown in Figs. 14 and 15, the mouths pointing backwards.
On the one side is fixed a charging gallery, along which
the metal is brought to supply the converters, and behind
which the repair shop is usually placed. This gallery is at
such an elevation that the metal can be poured directly
into the converter, when the converter is brought over into
a horizontal position.

On the other side of the converter is the casting pit.
This is a circular pit about 20 ft. in diameter, and for
convenience sunk about 3 ft. below the floor level of the
shop. In the centre of the pit is fixed the ladle crane.
This is a long narrow platform carried on a support. It
carries the casting ladle at one end, and at the other,
which is much shorter, a shelter for the man in charge.
It is so arranged that the ladle can be brought under the
mouth of the converter to receive the metal, and then over
the moulds, which are arranged round the circumference
of the pit.

The ladle must be large enough to hold all the metal
from a charge, and also any slag, and it is provided with
a tap hole at the bottom by which the metal can be run
into the moulds.

The crane (Fig. 16) is controlled by the man in charge
of it, and it has two motions, the circular motion by which
it can be rotated so as to be brought under the mouth of
the converter, and also a vertical motion, worked by
hydraulic gear, so that it can be lowered when under the
converter and raised when over the moulds. The vertical
motion is sometimes dispensed with, but then the con-
verters must be placed inconveniently high.

In front of the pit is placed a raised platform (com-
monly called the pulpit), from which the foreman watches

the process, and, by means of a series of levers, controls
the motion of the converter and the blowing.

At convenient positions on each side of the pit are
placed the ingot cranes by which the moulds can be lifted
into place, and the ingots of metal lifted away. These
are so placed that they command every part of the pit.

Rails are also laid so that the ingots can be carried
away on trucks, and also to the repair shop, so that the
portion of the converter can be removed as required.

On the platform also is usually a small cupola and
a heating furnace, by which the ferro-manganese can be
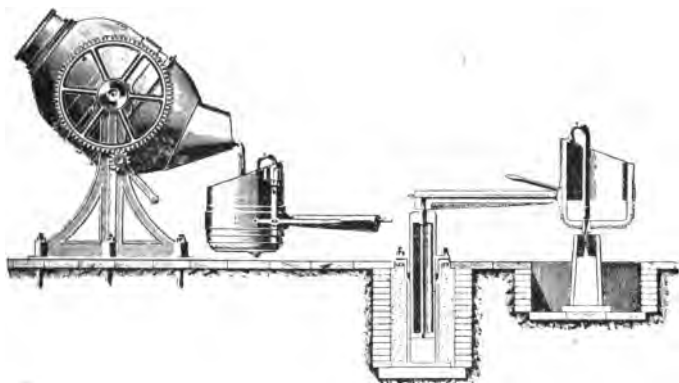
Fig. 16.—Bessemer Crane.

melted or heated according to the condition in which it is
to be added to the charge.

The Blowing Engine.—The air supply is, of course, very
important. The quantity of air required is not very large,
being about ·58 ton for each ton of iron, or for a 10-ton
charge 5·8 tons, and as the blow will occupy somewhere
about 20 minutes, the amount of air required will be a
little over 800 cub. ft. per minute, the amount of course
varying with the quantity of oxidisable materials to be
removed from the iron. The pressure must be sufficient
to enable a rapid current of air to pass through the
molten metal, and is usually from 10 to 25 lb. per sq. in.

The engines are almost always direct acting, and may

be either horizontal or vertical, and are worked in pairs so as to give as steady a pressure as possible.

Working a Charge.—The converter is turned on its side so that the mouth is horizontal. The metal is brought up in a ladle and is poured by means of a fire-clay lined shoot into the converter. The converter must be so shaped that when it is horizontal the metal lies quite clear of the tuyeres. As soon as the metal is in, the shoot is withdrawn, the blast is put on, and the converter is slowly turned up. As the metal flows over the tuyeres, the air forcing its way through the comparatively thin sheet of metal, breaks it up and causes a vigorous ejection of sparks— minute fragments of molten iron. As the metal becomes deeper over the tuyeres the ejection of sparks diminishes but does not entirely cease. As soon as the converter is up the reactions become very vigorous. At first there is very little flame, only a stream of hot gas and a shower of sparks coming from the mouth of the converter. In a few minutes a decided flame makes its appearance at the mouth of the converter; it is, however, small and but slightly luminous. After 5 or 6 minutes or longer, during which time the temperature is rapidly rising, the flame becomes larger and more luminous. At first it is very unsteady, but it gradually increases in steadiness, density, and luminosity, showers of sparks and minute fragments of iron, which burn as they come into the air, being ejected. After another ten minutes or so the flame begins to flutter, becomes less luminous and less dense, and diminishes in volume. The foreman now watches carefully, and all at once the flame suddenly diminishes or drops, and the blow is over. Then, without a moment's delay, the converter is once more turned down. All the carbon and silicon have by this time been removed, but oxygen has also been taken up, and if the metal were poured the resulting steel would be " rotten " and useless.

A certain quantity of speigeleisen or ferro-manganese is then added, and the metal is ready for pouring. The ferro-manganese is either thrown into the converter or into the metal as it flows into the ladle. It is added cold if only a small quantity is required, hot if more is being used, and if the quantity is large it is often melted and run in in the liquid condition.

The metal and slag are then poured into the ladle, and the metal is distributed to the moulds. As soon as the ladle is moved away the converter is upended, and some very refractory slag which has not poured with the metal is run out, and falls on to the floor of the pit. The converter is then turned horizontal again, the man in charge examines the inside, and if the lining is cut away anywhere it is patched by throwing in ganister and pressing it into place by means of iron rods.

As soon as the converter is turned down, a charge of metal is run into the second converter, and another blow is started, so that with two converters 10 tons of pig iron will be converted into steel every 20 minutes.

Chemistry of the Process.—The chemistry of the process is quite simple in its general principles. As the air is blown through, the easily oxidisable constituents are removed, together with some of the iron. It is probable that the action is indirect. The air, coming in contact with the iron, probably at once forms magnetic oxide of iron (Fe_3O_4), which is then decomposed by the carbon, silicon and other oxidisable constituents present.

Immediately the blow commences the oxidation of the silicon begins and the temperature rises, thus Fe_3O_4 + Si = Fe_2SiO_4 + Fe. The oxygen is thus absorbed, and the gas which leaves the converter is mainly the nitrogen from the air. As the action goes on the carbon is attacked. Fe_3O_4 + $2C$ = $3Fe$ + $2CO_2$ and Fe_3O_4 + $4C$ = $3Fe$ + $4CO$. At first the carbon is largely burnt to carbon dioxide, but as the temperature rises carbon monoxide is the main product, and the gas therefore is combustible and burns at the mouth of the producer, forming the flame. If there is any manganese in the iron it will be oxidised very early in the blow, and will pass into the slag as silicate of manganese. Sulphur is not removed at all, nor is phosphorus; indeed, the latter element seems to increase, because as the blow goes on the quantity of metal through which it is distributed is reduced. The non-removal of the phosphorus is due to the large quantity of silica present in the lining of the converter and in contact with the metal, because the only form in which the phosphorus can pass out is as phosphate of iron, and this is decomposed of silica, phosphoric oxide being liberated and de-

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composed by the hot iron with the formation of iron phosphide and oxide. As the constituents are oxidised out, the steel produced must be less in quantity than the iron used, as will be seen from the figures below :—

	Composition of the Iron.	*Left in Steel.*	*Loss.*
Carbon	3·5	·1	3 4
Silicon , ...	2·5	·1	2·4
Iron required to form silicate ⎫ with the silica, assuming ⎬ the slag to be 2FeO SiO₂ ⎭	—	—	9 6
		Total loss	15·4

The loss may be either greater or less than this estimate, because the slag may be either more basic or more acid. Any manganese present will combine with some of the silica, and thus tend to reduce the loss of iron.

The following analyses of the metal at different stages of a blow will indicate the way in which the impurities are removed.

ANALYSES OF PIG-IRON, AND OF THE BESSEMER CHARGE AT DIFFERENT PERIODS OF THE BLOW IN THE NEUBERG WORKS.

	Grey pig-iron smelted with char-coal from spathic iron-ores.	*Metal at the end of the first stage of the blow.*	*Metal towards the end of the boil.*	*Metal before the addition of spiegel-eisen.*	*Final product of mild steel.*
Graphite ...	3·180	—	—	—	—
Combined carbon	0·750	2·465	0·949	0·087	0·234
Silicon	1·960	0·443	0·112	0·028	0·033
Phosphorus ...	0·040	0·040	0·045	0·045	0·044
Sulphur... ...	0·018	trace	trace	trace	trace
Manganese ...	3·460	1·645	0·429	0·113	0·139
Copper	0·080	0·091	0·095	0·120	0·105
Iron	90·501	95·316	98·370	99·607	99·445
	99·989	100·000	100·000	100·000	100·000

ANALYSES OF THE PIG-IRON AND OF THE BESSEMER CHARGE AT DIFFERENT STAGES OF THE BLOW, &C., AS PRODUCED IN THE DOWLAIS WORKS.

	Melted pig-iron as charged into the converter.	*Metal from the converter at the end of the first stage of the blow.*	*Metal after blowing for 9 minutes.*	*Metal at end of blow and before the addition of spiegeleisen.*	*Steel from the cast ingot.*	*Steel from the rolled rail.*
Graphitic carbon	2·070	—	—	—	—	—
Combined carbon	1·200	2·170	1·550	0·097	0·566	0·519
Silicon	1·952	0·790	0·635	0·020	0·030	0·030
Sulphur... ...	0·014	trace	trace	trace	trace	trace
Phosphorus ...	0·048	0·051	0·064	0·067	0·055	0·053
Manganese ...	0·086	trace	trace	trace	0·309	0·309
Copper	—	—	—	—	0·039	0·039

Sources of Heat.—As already remarked, the heat evolved by the oxidation of the various constituents removed from the iron is sufficient to keep the whole in a molten condition. Knowing the composition of the pig iron used and the heat of combustion of the various constituents, it is easy to calculate approximately what the heat evolved would be.

For example :—

	Composition of pig-iron.	*Percentage of elements not oxidised.*	*Elements oxidised.*
Carbon	3·5	·10	3·4
Silicon	2·5	·10	2·4
Sulphur	·05	·05	—
Phosphorus	·06	·06	—
Manganese...	1·0	—	1·0
Iron	—	— (say)	5·0

The carbon is partly oxidised to carbon-dioxide and partly to carbon-monoxide. It will not be far out if it be assumed that one-third of the carbon leaves the converter as carbon-dioxide and two-thirds as carbon-monoxide. In this case, since the calorific power of carbon burning to carbon-dioxide is 8080, and burning to carbon-monoxide it is 2400, the heat evolved by the combustion of each pound of carbon will be $\dfrac{8080 + 2 \times 2400}{3} = 4293$ centigrade units.

The calorific power of silicon is 7830 c.u.

The calorific power of manganese burning to manganese oxide is 1724 c.u.

The calorific power of iron is 1582, so that, putting these together, the heat evolved by the combustion of the oxidisable constituents from 100 lb. of the iron would be :—

Carbon	...	...	$3\cdot4 \times 4293$	$=$	14596
Silicon	...	...	$2\cdot4 \times 7830$	$=$	18792
Manganese	...	..	1×1724	$=$	1724
Iron	...	...	5×1528	$=$	7640
					42752 c. u.

Or each 100 lb. of the pig iron during conversion into steel will evolve 42752 units of heat. The actual amount may, of course, be larger or smaller according to the composition of the pig iron used and the amount of iron oxidised.

The specific heat of iron being ·113795, this amount of heat would, if there were no loss of heat, raise 100 lb. of iron to a temperature of over 3700° C. above its initial temperature.

One pound of good coal gives a combustion of about 8000 units of heat, so that the heat evolved in the converter per 100 lb. of iron will be equal to that given by the combustion of about 5·3 lb. of coal, or from the 10 tons heat about equal to that given by the combustion of 1,187 lb. or nearly 10 cwt. of coal. Imagine 10 cwt. of coal to be burnt in a small vessel in 20 minutes, and it will not be difficult to see that a very high temperature must be produced.

The calculations given above are not strictly accurate, because it is assumed that the elements oxidised give the same amount of heat as they would do if burnt in the free condition. As they are present in combination this is certainly not the case, but the compounds in which the oxidisable elements exist in iron are formed with the evolution or absorption of such small quantities of heat that the figures given are quite near enough for the purpose.

At the end of the blow the iron contains a certain amount of oxygen, probably as oxide of iron, which is taken up by the manganese added in the ferro-manganese. As the heat of oxidation of manganese is greater than that

of iron the exchange causes an evolution of heat, which still further tends to raise the temperature of the metal.

Effect of the Ferro-manganese.—At the end of the blow the carbon in the metal will have been reduced to about 0·1 per cent., and, as already remarked, oxygen will have been taken up. As the steel will rarely be required to contain as little as 0·1 per cent. of carbon, it is necessary to add more. This is done by the addition of the speigeleisen of ferro-manganese,* which is therefore called the recarburiser. The function of the recarburiser is twofold: (1) to add the required amount of carbon; (2) to add sufficient manganese to remove the oxygen. The amount to be added is calculated from the amount of carbon required, and the richer the ferromanganese the less will be needed to give the required amount of manganese. Should the manganese be insufficient in quantity some of the carbon would be oxidised, and the resulting steel would be too low in carbon. A slight excess of manganese is therefore always added.

Selection of Pig Iron.—The selection of pig iron for the Bessemer process is of great importance. A pig specially suitable is now largely made under the name of Bessemer or hæmatite pig.

Since phosphorus and sulphur are not removed during the process it is obvious that the pig iron used must be as free as possible from these elements. The limits usually fixed by British steel makers are: Phosphorus, 0·06 per cent.; sulphur, 0·05 per cent. American steel makers allow a slightly higher percentage of phosphorus.

The amount of carbon present in unimportant, as there is always sufficient present in pig iron made under the conditions necessary for the production of a hæmatite pig.

The amount of silicon is very important. British steelmakers prefer about 2·5 per cent., and specify not less than 2, or more than 3, per cent.

If the silicon is too high the blow will be too hot, for, as has been already pointed out, the silicon is the chief source of heat in the blow. A blow which

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* Ferro-manganese may contain up to 85 per cent. of manganese and about 7 per cent. of carbon. Spiegeleisen contains about 25 per cent. of manganese.

is too hot gives an inferior steel. As the temperature becomes very high the carbon is apt to be oxidised out before the silicon, because at very high temperatures carbon will decompose silica, liberating silicon. As the drop of the flame by which the end of the blow is determined depends on the elimination of the carbon only, the flame might drop before the silicon was all out, and thus silicon in objectionable quantity might be left. When the blow seems to be getting too hot, the converter is turned down and a few hundredweight of cold steel scrap is added. This cools the charge and serves to dilute the silicon.

As the silicon leaves the converter as silicate of iron, as a rule the larger the amount of silicon in the iron the greater will be the loss of iron in the slag.

Too low silicon is also objectionable, because the blow is apt to be cold, especially during the early stages, and " skulls " of solid metal may be formed which are difficult to remelt.

The Bessemer process, therefore, requires a pig iron the composition of which must vary only within narrow limits.

Loss and Gain of Heat in the Blow.—The heat of the blow is :—

(1.) That carried in by the molten metal.

(2.) That carried in by the air.

(3.) That evolved in the converter by the combustion of the oxidisable constituents during the blow.

The heat carried out is :—

(1.) That carried out by the hot metal.

(2.) That carried out by the gases.

(3.) That lost by radiation.

The metal which leaves the converter must be very hot, as it is not very fusible. When the composition of the pig iron used is such that the amount of heat evolved is comparatively small, heat must be supplied by other means, or the loss of heat must be reduced. It has been suggested to heat the metal very strongly before putting it into the converter, and also to heat the air, but neither of these methods has come largely into use, so that the heat of combustion is the only source of heat that can be depended upon.

The heat carried out by the gases cannot be reduced, but that lost by radiation can be reduced to some extent by quick working, because it takes place largely whilst the converter is standing empty between the blows.

American Bessemer Practice.—In America the pig iron used is much lower in silicon than that used in this country, containing usually from 1 to 1·5 per cent. of silicon only, the average being about 1·25. It is obvious that with such an iron the amount of heat evolved will be small, and also that the blow will be short, as the time mainly depends on the amount of silicon present. As the blows are very short the converters stand empty a much shorter time, and therefore the loss of heat by radiation is much smaller.

In America the time of blow ranges from about 7 to 12 minutes, averaging probably about 9. The output of a given plant is therefore much larger than in this country, but the work is much harder on the men, and the plant has to be arranged so as to deal with the large output. The quality of the steel does not seem to be altered in any way by the quick working.

Modifications of Bessemer Plant.—The form of the converter and the arrangement of the plant may be modified without in any way altering the principles of the process or even the details of working.

The hood of the converter may be made vertical instead of the usual inclined form, the mouth in that case being horizontal. This has the advantage that the pasty slag is more easily removed, but the disadvantage that, unless the converter is worked tilted, the sparks are more likely to be thrown on to the platform.

The converters may be arranged in a row pointing backwards instead of back to back, and a set may be three instead of two, so that there will always be a spare one to use while one is being relined. The circular casting pit may be replaced by a longitudinal pit such as will be described in connection with the open-hearth steel process, or the ladle may be transferred to a second crane, and two circular pits used for each pair of converters.

The modifications of the plant are indeed almost endless, each engineer designing the plant to suit the requirements of the works.

The Products.

The Steel.—The Bessemer process is almost entirely used for making steel of comparatively low carbon content. Since the carbon is added in the form of ferro-manganese, the addition of a large percentage of carbon would mean the use of a large quantity of ferro-manganese, and this would introduce a considerable quantity of impurities which might be deleterious. Steel containing over 0·5 per cent. of carbon is therefore rarely made. The end of the process is determined by the drop of the flame, and the turning of the converter must be very prompt, otherwise the metal will be overblown. Unless, therefore, the work is most carefully done the steel tends to be somewhat irregular in composition.

The Slag.—The quantity of slag produced varies with the composition of the iron. As a rule, it will be about 1·5 cwt. per ton of iron, but may vary up or down very considerably. The slag is essentially a silicate of iron or manganese, varying between the types RO,SiO_2 and $2RO,SiO_2$. It always contains small quantities of lime, alumina, and alkalies derived from the lining of the converter. There is always a small quantity of a very refractory siliceous material left in the converter after the metal is poured. The following analyses will give an idea of the nature of the slag :—

	1.	2.	3.
Silica	47·27	46·75	72·25
Alumina	3·45	2·80	2·43
Ferrous oxide ...	15·63	16·86	20·65
Manganese oxide ...	31·89	32·23	2·95
Lime	1·23	1·19	1·04
Magnesia	·61	·52	·13
Phosphorus	·0I	·01	—

No. 3 is a siliceous residue left in the converter.

The Gases.—The escaping gas consists of a mixture of nitrogen, carbon monoxide with carbon dioxide during the early part of the blow, and a small quantity of hydrogen.

During the early part of the blow the ·percentage of nitrogen is high, as oxygen is being absorbed by the oxidation of the silicon. The following analyses by Snelus will give an idea of the composition of the gas :—

ANALYSES OF THE GASES FROM THE MOUTH OF THE BESSEMER
CONVERTER. (SNELUS.)

	Time after commencement of blow.						After addition of Spiegeleisen at Bochum Works.
	Two minutes.	Four minutes.	Six minutes.	Ten minutes.	Twelve minutes.	Fourteen minutes.	
Carbonic anhydride	10·71	8·59	8·20	3·58	2·30	1·34	—	0·86
Carbonic oxide ...	None	3·95	4·52	19·59	29·30	31·11	82·6	78·55
Oxygen	0·92	—	—	—	—	—	—	1·32
Hydrogen ...	88·37	0·88	2·00	2 00	2·16	2·00	2 8	2·52
Nitrogen ...		86·58	85·28	74·83	66·24	65·55	14·3	16·38

The temperature of the flame and of the escaping gases from the Bessemer converter at any period of the blow falls below that required to melt a wire of platinum or of an alloy of platinum and iridium, when the same is held within the flame; whilst a wire of gold is always melted during the boil or towards the end of the blow; hence, since the melting-point of gold is about 1,300° C., and taking the melting-point of platinum as 2,000° C., it follows that the temperature of the flame rises to a point exceeding 1,300° C., but never attains to 2,000° C.

Durability of the Converter.—The bottom of the converter wears away rapidly, and may be used till it is reduced to about 6 in. in thickness. The actual life of the bottom depends upon various conditions : on the care with which it has been made, the size of the tuyere openings, and the pressure of the blast. The usual duration is about ten to twenty heats.

The life of the body-lining depends much on the care with which it has been made. It may vary from one month or less up to twelve months. Howe mentions one body which had lasted 3,000 blows.

Application of the Spectroscope to the Bessemer Process.—The spectroscope has been applied successfully to the analysis of the flame issuing from the mouth of the Bessemer vessel, and for the determination accordingly of the proper moment at which to turn down the converter and stop the blow; but the conclusion of the blow is of such easy practical determination to the practised

Bessemer man that the use of the spectroscope in the regular conduct of the process has not been extensive in England, but on the Continent it is more largely used. The principal phenomena observed at different periods of a blow lasting 24 minutes, as seen simultaneously by the naked eye and through the spectroscope, are herewith tabulated :—

PHENOMENA OBSERVED BY APPLICATION OF SPECTROSCOPE TO BESSEMER PROCESS.

Minutes from the commencement of the blow.	*Appearances presented to the naked eye.*	*Appearance of the spectrum.*
4	Very small flame with sparks of metal	Faint continuous spectrum.
5	Flame pale, but increasing in size	Continuous spectrum, with two yellow sodium lines flashing across it.
6	Large unsteady flame	Sodium lines steady and fixed.
8	Flame brighter and larger	Yellow sodium lines, with lines also in the red and violet bands, appear.
10	Boil commenced accompanied by bright dense flame	Spectrum as the last, but with additional lines appearing in the red, with carbon lines in the green and blue, and other manganese lines also in the green.
15	Flame becomes larger and more transparent	Spectrum more distinct and the lines better defined.
20	Less luminous and diminishing volume of flame	Spectrum as before, but fading in intensity.
24	Flame drops	Green lines in the carbon and manganese bands disappear

CHAPTER III.

THE BASIC BESSEMER PROCESS.

As already pointed out, the iron for the Bessemer process must be free from sulphur and phosphorus, and therefore the ordinary pig irons produced in the chief iron-smelting districts of Great Britain are quite unsuitable for steel-making by it. Many workers tried to so modify the process that it might be applicable to the treatment of phosphoric irons, such as those of Middlesbrough and Scotland. Snelus and others saw that what was necessary was to abolish the acid or ganister lining of the converter and replace it by some basic material, but the finding of a suitable material was the difficulty. This was overcome by Messrs. Thomas and Gilchrist, who, in 1877, introduced magnesian limestone (dolomite or dolomitic limestone) as the basis of a converter lining.

Principle.—The impurities are oxidised out by blowing air through the molten iron till the carbon and silicon are removed, and subsequently recarburising by the addition of ferro-manganese, as in the Bessemer process. The converter is, however, lined with a basic material instead of with siliceous ganister. The drop of the flame is not as marked as in the Bessemer process, and, as there, it indicates the removal of all the carbon, but so much phosphorus is still left that the blow must be continued (the after-blow) till this is all oxidised. As there is no external indication of the end of the blow, samples are taken and examined to determine when the blow is over,

The Plant.—The plant used is identical with that used in the Bessemer process, except that the converters must either be made larger or smaller charges must be worked. A 10-ton acid converter will hold about 7 tons when worked basic. The converter also has generally a straight hood, and the mouth therefore is parallel with the bottom (see Fig. 17).

Lining the Converter.—The lining of the converter is almost always the dolomitic or magnesian limestone of the North of England. Dolomite is a double carbonate of lime and magnesia, $CaCO_3MgCO_3$, and the magnesian limestone consists of this mineral, sometimes with an excess of calcium carbonate and with a small percentage of silica. The quantity of silica usually present is about 4 per cent., and 8 per cent. is about the limit allowable.

Fig. 17.—Basic Bessemer Converter.

When the magnesian limestone is heated to whiteness the carbon dioxide is expelled, and the material shrinks very much, a magnesia-lime being left which slakes very much less readily on exposure to the air than does a purer lime. In order that this " lime " may bind so as to hold together until the temperature is high enough to enable the silica present to frit it into a solid mass, some binding material must be used, and the one selected by Messrs. Thomas and Gilchrist, and which is now generally used, is boiled or anhydrous tar—*i.e.* tar which has been heated till all the water has been expelled. Obviously tar containing water could not be used, as it would cause slaking of the lime.

The burnt dolomite is ground to a coarse powder (about ⅛ in.), and is then mixed with the hot tar in a mill, the amount of tar required being 7 to 12 per cent. of the weight of the dolomite.

Sometimes, in place of magnesian limestone, magnesite or magnesium carbonate is used.

The converter, as in the case of the acid process, is lined in three parts.

Sometimes tuyeres of a basic material are used, being adjusted exactly as in the ordinary Bessemer converter, but more usually a pin bottom—*i.e.* one in which the holes for the passage of the air are made through the bottom itself—is used. A plug is first made; this is a cylinder of basic material the size of the bottom plate of the converter bottom. A bottom plate, provided with a large number (about 50 to 80) of pins, about ½ in. in diameter, is surrounded by an iron cylinder. The magnesia tar mixture is then spread in thin layers, and is stamped down by means of hot iron rammers till it has a thickness of about 15 to 18 in., 40 or 50 layers being required. The plug is then lifted away, and the withdrawal of the pins leaves a large number of holes through it, which act as tuyeres for the passage of the air. The plug is then lowered into the centre of the converter bottom, and the space between it and the iron shell is rammed in with the hot tar mixture. The finished bottom is then covered with a layer of powdered dolomite, iron ore, or other material to exclude air, is placed on a carriage and run into an oven, where it is strongly heated for some hours. In place of hand-ramming, hydraulic pressure is now occasionally used.

The body may be lined in several ways, the usual way being by means of bricks. The magnesia-lime-tar mixture is made into bricks by pressing in a hydraulic press, and these bricks are set in a magnesia-lime-tar mortar, or the lining may be made by ramming; in this case a wooden core is placed in the body casing and the magnesia-lime-tar mixture is rammed in by means of hot rammers.

The hood may be lined either with bricks or by ramming. The joint between the parts of the converter is made with a mortar of the same materials as are used for the lining itself. The three parts of the converter are put

together and a fire is lighted inside to warm and dry it
before it is put into use.

In a plant for the basic process an upper gallery or
gantry is provided at a higher level than the charging
platform, from which lime and, if necessary, scrap can
be charged without turning the converter down.

The Blow.—The converter, being hot from the previous
charge, is turned into the required position and a quan-
tity of unslaked lime is put in from a truck. The object
of the lime is to supply material for the slag, and thus
as far as possible to save the lining of the converter from
corrosion. The amount required varies from about 10 to
20 per cent. of the weight of the charge, 15 per cent. being
perhaps about the average. Allowing 15 per cent. for a
10-ton charge, the amount would be 1˙5 tons, or 3,360 lb.,
and, as a cub. yd. of lime weighs about 1,200 lb., this will
be about 2˙75 cub. yds. It will be seen, therefore, why
the converter must be larger for the basic than for the acid
process. The lime must be freshly calcined, well burnt,
and as free as possible from silica and phosphorus.

The converter is now turned down and charged exactly
as in the ordinary Bessemer process, the blast put on, and
it is then turned up. A vigorous ejection of sparks begins
as the iron flows over the tuyeres and continues more or
less during the whole blow. The flame is similar to that
of the ordinary blow, and goes through the same changes.
When the carbon is all removed the flame drops, but the
blow is not yet over, for though the silicon and carbon
have been oxidised out the phosphorus still remains, and
the blow must be continued till this is gone, this extra
time of blow being called the " after blow." There is no
well-marked indication of the point when the phosphorus
is removed, so the " blower " in charge continues the blow
as long as he thinks necessary. Then the converter is
turned down, and by means of a ladle on a long handle
a sample of metal is taken from the converter and cast
into a small ingot. This ingot is flattened under a steam-
hammer and then is broken across, and by the fracture
the condition of the metal can be judged. The presence
of even a small quantity of phosphorus imparts a coarsely
crystalline structure to the metal, and as the phosphorus
is removed the structure becomes finer and finer, and ulti-

mately becomes that of normal steel. From the appearance, the condition of the metal and the further blowing required is judged. Then the converter is turned up and the blow resumed for the necessary time ; it is then turned down again, another sample is taken, and so on till the sample is satisfactory. As soon as a satisfactory sample is obtained, the slag is carefully poured off into a slag bogie, leaving the surface of the metal as clean as possible ; lime is added to stiffen the slag which remains, and the metal is then poured into the ladle, any slag being kept back with an iron rod, and the recarburiser is added as the metal flows, and the metal is teemed into the moulds as usual. As soon as the metal is all out the converter is turned down, the residual slag poured out; then it is turned up, the interior examined and repaired if necessary by the addition of a mixture of magnesian limestone and tar, and it is ready for the next blow.

The slag must all be poured off before the recarburiser is added, or phosphorus would be reduced from the slag and pass into the metal.

The blow takes about 20 minutes, though it may be longer or shorter according to the composition of the iron. Towards the end of the blow, after the silicon is all removed, a dense brown smoke is given off from the converter, which is probably mainly oxide of iron.

It will be seen that the blow differs in several respects from the acid blow. (1) Lime is added; (2) the blow is not over when the flame drops ; (3) red smoke is given off ; (4) the slag is poured off as completely as possible before the recarburiser is added. The loss of iron is also considerably greater than in the acid blow.

Chemistry of the Process.—The chemical changes are very similar to those which take place during an acid blow, though there are some marked differences.

The silicon is removed more rapidly and completely, because of the large amount of base (lime) ready to combine with the silica formed, and also perhaps because the temperature of the blow in the early stages is lower. By the time the flame drops every trace of silicon has been oxidised out.

The carbon is also very rapidly removed. As in the acid process, the flame drops when the residual carbon

is about ˙1 per cent., and during the after-blow this is removed.

Manganese is much more slowly removed than in the acid process, because it passes out as manganese silicate, and there is but little silica to combine with it.

The removal of the phosphorus is the most important reaction in the whole process. No phosphorus is oxidised during the earlier period of the blow, and very little until the flame drops. After that the oxidation is very rapid, and at the end almost the whole of the phosphorus is removed.

Sulphur is removed only to a small extent; a little, however, passes into the slag.

The following analyses of steel at various periods of a blow will illustrate the way in which the various constituents are oxidised out :—

ANALYSES OF METAL AT VARIOUS PERIODS OF THE BASIC BESSEMER PROCESS AS CONDUCTED AT ESTON.

	Original pig-iron.	Metal after blowing for					Steel after addition of spiegel.
		6 min.	12 min.	14½ min. or end of ordinary blow.	16¼ min.	16 min. 35 sec. or at end of after-blow.	
Carbon ...	3·57	3·40	0·88	0·07	trace	trace	0·124
Silicon ...	1·70	0·28	0·01	trace	nil	nil	0·030
Phosphorus...	1·57	1·63	1·42	1·22	0·14	0·08	0·22
Manganese ...	0·71	0·56	0·27	0·12	0·10	trace	0·270
Sulphur ...	0·06	0·06	0·05	0·05	0·05	0·05	0·04

ANALYSES OF THE CHARGE IN THE BASIC-LINED CONVERTER AT THE RHENISH STEEL WORKS. (JORDAN.)

	Original pig-iron from the cupola.	After blowing 10 min.	After 2 min. overblow or 15¼ min. from the commencement.	Steel after addition of spiegel.
Carbon	3·276	0·590	0·026	0·302
Silicon	0·476	0·222	0·002	0·016
Phosphorus	2·600	2·064	0·062	0·092
Manganese	1·131	0·122	0·197	0·540
Sulphur	0·062	0·139	0·051	0·040

In both these blows the phosphorus is considerably lower than is now generally used, but this only necessitates a shorter after-blow. As will be seen from the second series of analyses, a small quantity of phosphorus is re-reduced on the addition of the recarburiser.

Source of Heat in the Blow.—The principal source of heat is of course the oxidation of the oxidisable constituents in the pig iron, but the distribution of heat is somewhat different from that in the acid process. The silicon is oxidised very rapidly at the outset, and is followed by the carbon, but as the silicon is much lower than in ordinary Bessemer pig, the temperature at the beginning of the blow is lower. When the after-blow commences the phosphorus begins to oxidise, and rapidly brings up the temperature so that the metal is hot enough to pour.

Assuming the composition of the pig iron used and the amount of impurities left in the steel to be as under, the actual heat evolved can easily be calculated.

	Pig iron.	Elements left in steel.	Oxidised.		C.P.	Heat evolved.
Carbon	3·5	—	3·5	×	4150	14525
Silicon	1·0	—	1·0	×	7830	7830
Manganese ...	2·0	·1	1·9	×	1724	3275
Phosphorus ...	3·0	·08	2 92	×	5868	17134
Iron	—	—	15 0	×	1582	23730

Total heat per hundred lb. of pig iron ... 66494

From this, however, there is a small deduction that should be made, though it is not of any very great importance. The phosphorus is present in the iron as a definite phosphide (Fe_3P), and therefore for each one part of phosphorus oxidised 6·42 parts of the phosphide must be decomposed. The heat of formation of the phosphide is about 3,247 units for each part of phosphorus, so that for the 2·92 per cent. of phosphorus the heat absorbed by the decomposition of the phosphide would be 2·92 × 3,247 = 9,481 units to be deducted. Against this may be set the heat evolved by the union of the lime with the phosphoric-anhydride to form calcium-phosphate. Each molecule of calcium-phosphate ($3CaOP_2O_5$) formed by the union of lime and phosphoric-anhydride gives 33,000 units of heat, and as the phosphate contains 20 per

D

cent. of phosphorus, each one part of phosphorus will evolve 6,600 units of heat, so that the full statement of the heat evolved would be :—

Heat evolved by oxidation as above	66494
Heat evolved by the formation of calcium phosphate from lime and phosphoric acid, 6600 × 2·92	19272
	85766
Less heat absorbed by decomposition of iron phosphide ...	9481
Net heat evolution	76285

It must, of course, be understood that these figures are not to be regarded as being strictly accurate, but only as being approximations to the actual heat evolved.

Selection of Pig Iron.—The object with which the basic Bessemer process was sought and ultimately discovered was to allow of the use of such pig irons as those of Cleveland and Scotland for steel-making. This object was not altogether attained, for it was soon found that these irons did not contain sufficient phosphorus, and that it was better, therefore, to make a special iron for the purpose. The iron made for this purpose is called Basic pig. It will be understood that it has no basic properties, but that it derives its name from the fact that it is used for the manufacture of steel in basic-lined converters by the so-called " basic " process.

A good basic pig should be low in silicon, usually not containing more than 1 per cent. and sometimes even less. A large percentage of silicon is objectionable, as it prolongs the blow, causes the blow to be " hot," and at the same time necessitates the use of a large quantity of lime; but any amount of silicon would be ultimately removed during the blow. Owing to the small percentage of silicon the iron is usually white, whilst Bessemer pig, which contains a large quantity of silicon, is almost always grey.

The amount of carbon is immaterial, but is usually from 3 to 3·5 per cent.

The amount of manganese should be from 2 to 3 per cent. The manganese tends to the elimination of sulphur from the pig iron, and by its oxidation, which is spread over the whole time of the blow, it tends to give a steady evolution of heat.

The amount of phosphorus should be from 2 to 3·5 per cent. If the phosphorus be too low, the blow may be cold at the end, when it is most important to have the metal hot enough to pour well.

The Steel.—The steel may be made, if required, milder than is possible by the acid process, as the carbon is more completely removed during the blow. Unless the greatest care is taken phosphorus may remain in the metal or may be reduced from the slag. For this reason basic Bessemer steel is never used for purposes where a small quantity of phosphorus would be very objectionable. Steels higher in carbon than about 0·5 per cent. are never made.

The Slag.—The slag consists mainly of a mixture of silicate or phosphate of lime. Definite crystals of a tetra-calcic phosphate, $4CaO,P_2O_5,(Ca_4P_2O_9)$, have been obtained, and it is probable that the phosphorus is mainly present in this form. Ordinary tricalcic phosphate $(Ca_3P_2O_8)$, however finely ground, is only very slowly assimilated by plants, but the phosphorus in the basic slag is rapidly taken up, and there is therefore a large demand for basic slag as a manure. The slag is very finely ground and put into bags for the market.

The amount of phosphoric anhydride present varies from about 12 to about 22 per cent., and in order to secure a good slag for manurial purposes an iron high in phosphorus must be used.

An average good quality basic slag will contain about

Phosphoric acid ...	...	...	...	20	per cent.
Silica ...	...	...	...	6	,,
Lime ...	...	...	...	46	,,
Magnesia ...	...	...	...	6	,,
Ferrous oxide ...	...	...	...	13	,,
Ferric oxide ...	...	...	...	2	,,
Manganous oxide	...	...	...	5	,,
Alumina, etc. ...	...	...	...	2	,,
				100	

CHAPTER IV.

MODIFICATIONS OF THE BESSEMER PROCESS.

Bessemer Original Process.—The process as first used by Bessemer, and as carried out by him for about two years at his works in Sheffield, differed from the process as now worked which has just been described. Bessemer found that when the blow was continued till all the carbon was removed the steel was brittle or rotten, and as he had not
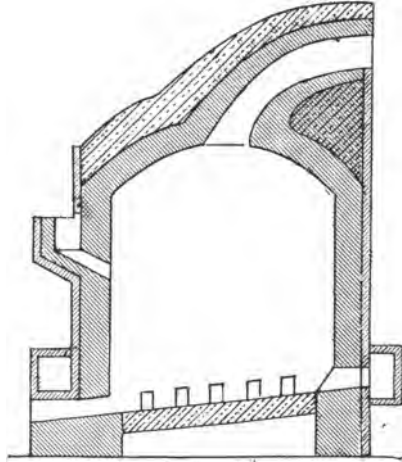
Fig. 18.—Swedish Fixed Converter.

adopted the use of manganese as a deoxidiser, as suggested by Mushet, the process in that form could not be carried out. Bessemer therefore stopped the blows at a point when a considerable quantity of carbon was left, and when therefore no oxygen could be taken up by the iron, and he thus made a high carbon steel, which could be used for tool-making, direct. In order that this might be done it was necessary to use an iron low in silicon, such as

. Swedish cold blast iron. When the use of manganese was discovered, and therefore very mild steels could be made, the demand for these became so great that the original process was abandoned and has never been revived in this ·country.

Swedish Method.—In Sweden Bessemer's original process was put in practice even before Bessemer had started his works in this country. The converters used were, however, very different to those ultimately adopted by Bessemer, and resembled those used in some of his earlier experiments. The converter, Fig. 18, was fixed instead of being able to tilt, and therefore the metal had to be tapped out, and the blowing continued until the metal was all out.

The first converter consisted of an iron casing, lined with ganister, about 4 ft. in diameter and 4 ft. high. At one side was an opening by which the molten metal could be run in, a tap hole by which the steel could be tapped out, and at the top a hood to carry off the products of combustion. Round the lower part of the converter was an air belt, communicating with the interior of the converter by a series of openings, just at the bottom, and the bottom itself was sloped towards the tap-hole, so that the metal would flow out when the tap-hole was opened. The converter being hot, the blast was put on, and the charge, about 1 ton of pig iron, was run in. As soon as it was judged that the oxidation had been continued sufficiently long the tap-hole was opened and the metal tapped out into the moulds.

At the present time the converters used in Sweden are of the usual tilting type, but are of small size, having a capacity of about 3 tons. They are acid lined, and are worked exactly in the usual way. Owing to the small percentage of silicon usually present in the iron, the blow is comparatively cold, and when the metal was run into the ladles it tended to chill round the outside and form " skulls," which were very difficult to remove. This trouble is overcome by the use of Casperson's Converter Ladle (Fig. 19). This is a small ladle which is attached to the mouth of the converter and into which the metal is run in small quantities at a time. The ladle is provided with a tap-hole and plug exactly as in the ordinary

large ladles, but instead of the ladle being moved over the moulds as in the ordinary plant, the moulds are brought under the ladle to receive the metal. Of course, the metal still containing a considerable quantity of carbon, is much more fusible than the nearly carbon-free metal obtained in the usual process.

The iron used is Swedish iron, nearly free from phosphorus and sulphur, and containing only a small percentage of silicon, 1 per cent. or even less being common. The converter being hot, the molten metal is run in in the usual way, and the converter turned up. There is,
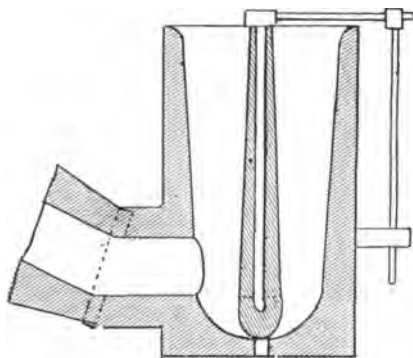
Fig. 19.—Casperson's Converter Ladle.

of course, no external indication as to when the metal has been sufficiently blown, so the blower uses his judgment, turns down the converter when he thinks the time has arrived, and takes a sample by means of a long spoon, and pours it into a mould. The sample is hammered and broken, and from it the condition of the metal is determined. If necessary, the converter is turned up again, and, as soon as a good test is obtained, the metal, with or without the addition of a little ferro-manganese, is poured into the moulds.

Bessemer steel containing from 1 to 1·5 per cent. of carbon is largely made by this process, and it is imported into this and other countries, where it is often melted in crucibles to make crucible cast steel.

The loss of iron is very considerable, varying from 9 to 12 per cent.

In order that the process may be successfully carried out, it is essential that the iron be low in silicon, and it should also be of very uniform composition, so that the end may be nearly hit by the time occupied in the blow.

Since the introduction of larger blast furnaces and the hot blast into Sweden, iron is often made containing 2 per cent. or more of silicon. This is converted into steel in the usual way of blowing till the flame drops, and then adding ferro-manganese.

Side-blown Converters. — In the converters usually used the air is blown in at the bottom; they are therefore called bottom-blown converters, but many converters have been designed in which the air blown is not at the bottom but at the side, and are called side-blown converters. The use of these converters necessitates some modifications in the method of working. It will be sufficient here to describe the one which is now most largely employed.

The Tropenas Process.—This process is mainly used for the manufacture of steel in small quantities for castings, and for this purpose a high temperature must be attained.

The converter is circular in form, externally not unlike the ordinary converter, but much smaller, and it is supported on trunnions in the usual way. The bottom of the converter is tapered so as to expose a considerable surface of metal to the air and at the same time be of considerable depth. The tuyeres are on one side of the converter only, and are at such a height that when the converter is vertical they would be a little beneath the surface of the metal. As a rule, there are two rows of tuyeres, one a little above the other (Figs. 20 to 23). The molten metal is run into the converter, and it is placd at such an angle that the air plays upon the surface of the metal, not through it. When the evolution of carbon-monoxide becomes rapid, the converter is turned a little more upright and air is sent in from the second row of tuyeres, so as to burn the carbon-monoxide evolved to carbon-dioxide within the converter, and thus increase the temperature. Frequently, however, the upper row of tuyeres

is not used. It will be seen that the oxidation is mainly
brought about by the oxidising action of the slag, as in the
open-hearth process, and not by air passing through the
metal as in the ordinary Bessemer process.   The converter
may have either an acid or a basic lining.   The capacity
of the converters varies from about 10 cwt. up to 2 tons,
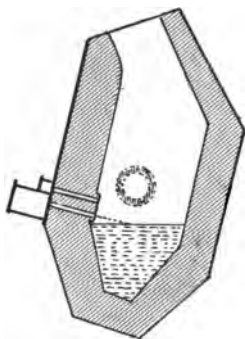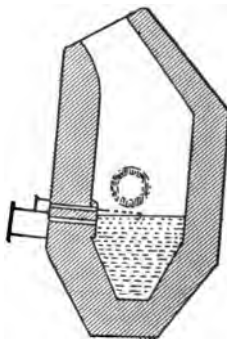
Fig. 20.   Fig. 21.

Figs. 20 and 21.—Sections of Tropenas Converter.
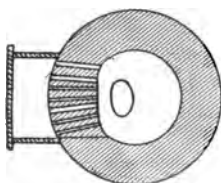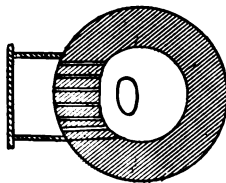
Fig. 22.   Fig. 23.

Figs. 22 and 23.—Plan of Tropenas Converter.

and the loss of iron during the time occupied by the blow
is said to be about 14 per cent.

Fixed Converters.—As already mentioned, the first con-
verters used in Sweden were fixed, the charge being tapped
out, and many modified forms of fixed converters have
been introduced, with more or less success, mainly for
working small charges. A fixed converter must be side
blown, and the tuyeres may either be at the bottom when
the converter is low blown or at a higher level, when it

is called a high-blown converter. (Fig. 24 shows Hatton's Fixed Converter.)

The blast must be started before the metal is run in, or at any rate before it reaches the tuyere level, and must be continued until the metal is all out of the converter. It often happens, therefore, that the metal towards the end of the tap is over-blown. Several de-
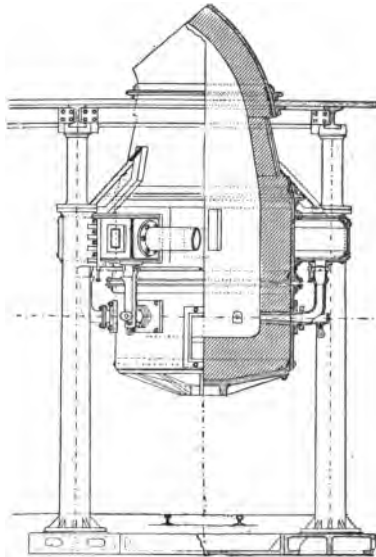
Fig. 24.—Hatton's Fixed Converter.

vices have been introduced for minimising the oxidation during tapping by reducing the blast to just sufficient to keep the metal out of the tuyeres.

If anything goes wrong with the tuyeres, or if there is delay in tapping, the charge will be spoiled and the metal must be scrapped. The loss of iron is usually higher with fixed converters than with those of the ordinary type, and red smoke usually escapes towards the end of the blow.

Small Converters.—The ordinary Bessemer process is

only suitable where a very large output is required, and many attempts have been made to obtain small outputs by the use of small converters varying in capacity from a few hundredweight up to one or two tons. Fixed converters have been used, or tilting converters blown at the side instead of at the bottom, or small bottom-blown converters of the usual type have been used, and the ladle has been dispensed with by lifting the whole converter by means of a crane and pouring the metal directly into the moulds.

The great trouble with small converters is the cooling due to radiation, and the difficulty, therefore, of keeping the metal hot enough to pour. The loss by oxidation is also larger than in the large converters.

History of the Bessemer Process.—Bessemer commenced his experiments on the manufacture of iron in the year 1852. By 1856 he had proved his method practicable, and at the meeting of the British Association at Cheltenham in the August of that year he read a paper giving an account of his process. He continued his experiments, and in 1858 the first practicable plant was erected in Sweden. In 1860 Bessemer started the works at Sheffield, where for the first time Bessemer steel was made in Great Britain. For the first two years the steel made was mainly tool steel, Swedish pig iron being used and the blow being left while there was still sufficient carbon for the purpose left in the metal. R. Mushet, who had heard Bessemer's first paper, suggested the use of manganese, and thus the difficulty in the manufacture of very mild steel was overcome.

In 1872, at the meeting of the Iron and Steel Institute, Mr. Ed. Snelus stated that he was working at the problem of the use of phosphoric irons in the Bessemer converter. Early in the seventies Messrs. S. G. Thomas and P. C. Gilchrist took up the matter, and about 1877 obtained satisfactory results, and their process was described before the Iron and Steel Institute in 1878.

CHAPTER V.

THE second modern process of steel-making, which is the great rival of the Bessemer process, is that known as the Siemens or open-hearth process. As this depends on the use of producer gas as fuel, and the regenerative furnace of Sir W. Siemens, it will be most convenient to describe these before passing to the actual process of steel-making.

Producer Gas.—Ordinary coal gas, made by distilling coal, would be an excellent fuel, but it is far too costly for use on the large scale. Only a small proportion of the coal used in making the gas is gasified, the larger proportion, 60 or 70 per cent., being left in the form of coke. In any system of gas production in which the gas must be very cheap the whole of the fuel must be gasified. This is done in the preparation of producer gas.

Principle.—When air is sent over red-hot coke, the coke burns, and if the temperature is high and the coke is in excess carbon-monoxide is produced; thus $C + O = CO$, any carbon-dioxide formed at first being decomposed by the hot coke, $CO_2 + C = 2CO$.

Air consists of about 79 per cent. of nitrogen and 21 per cent. of oxygen by volume, neglecting the other constituents, which are present only in small quantity. When carbon is burnt to carbon-monoxide, the carbon-monoxide occupies exactly twice the volume of the oxygen which it contains under the same conditions of temperature and pressure, so that if 100 volumes of air be taken, the 21 volumes of oxygen will yield 42 volumes of carbon-monoxide, and the resulting gas will contain 79 volumes of nitrogen and 42 volumes of carbon-monoxide, or its percentage composition will be

Carbon-monoxide	...	...	...	...	34·7
Nitrogen ...	...	...	...	...	65·3
					100·0

As carbon-monoxide and nitrogen have the same specific gravity, the composition of the gas by weight will be the same as its composition by volume.

Such a gas may be called simple producer gas. It is combustible, but has a very low calorific power.*

The calorific power of carbon-monoxide is 2430 C.U., so that that of the gas is ·347 × 2430 = 843 C.U., or 1489 B.Th.U.

The gas is produced by the partial combustion of the fuel, and this necessarily evolves heat.

One pound of carbon in burning forms 2⅓ lb. of carbon-monoxide, and evolves 2400 C.U. of heat (4320 B.Th.U.), and the 2⅓ lb. of carbon-monoxide, further burning, forms 3⅔ lb. of carbon-dioxide, and evolves 5680 C.U. (10220 B.Th.U.).

The former quantity is evolved in the producer, and is therefore largely, if not entirely, lost as far as heating the furnace is concerned, whilst the latter is evolved in the furnace and can therefore be usefully used. Thus, of the total 8080 C.U. which the 1 lb. of carbon gives on combustion, 2400, or nearly 30 per cent., is evolved in the producer, and is therefore lost. In practice there is always some carbon-dioxide in the gas, so that the evolution of heat in the producer and consequent loss is even greater.

Thus in simple producer gas the gas is very poor, and has been obtained at a cost of about 30 per cent. of the heating power of the fuel.

In order that producer gas may be successfully used it is necessary to obtain a better gas with a less loss of heat.

Steam-enriched Gas.—When steam is blown over red-hot coke it is decomposed, carbon-monoxide being formed and hydrogen liberated; thus $C + H_2O = CO + 2H$. It will be seen that the amount of carbon-monoxide produced is

---

* The calorific power is the number of units of heat evolved by the combustion of 1 lb. of the substance.

Two calorific units are in use. The C.U., which is used in this book, is the amount of heat required to raise 1 lb. of water 1° C. The British thermal unit, B.Th.U., is the amount of heat required to raise 1 lb. of water 1° F. The C.U. : the B.Th.U. as 9 : 5. So that

An amount of heat expressed by x C.U. is $\dfrac{x \times 9}{5}$ B.Th.U., and an amount of heat represented by y B.Th.U. is $\dfrac{y \times 5}{9}$ C.U.

exactly the same as if the carbon were burnt in air, but it is now accompanied by its own volume of combustible hydrogen instead of nearly twice its volume of inert and therefore useless nitrogen. The production of the mixture of hydrogen and carbon-monoxide from carbon and steam involves two changes, each of which will be accompanied by thermal changes, viz. water is decomposed and carbon-monoxide is formed, and for each gramme molecule—*i.e.* 18 grammes—of water decomposed, 1 gramme molecule— *i.e.* 28 grammes—of carbon-monoxide will be formed. The formation of carbon-monoxide evolves heat, but the decomposition of the water absorbs heat. Thus

$$
\begin{array}{llllll}
\text{Carbon monoxide} & = & 2400 & \times & 12 & = & 28800 + \\
\text{Water} & = & *29000 & \times & 2 & = & 58000 - \\
\hline
& & & & & & 29200 -
\end{array}
$$

Each 12 grammes of carbon burnt by steam therefore causes an absorption of about 29000 C.U.

It is quite obvious, therefore, that steam alone cannot be used, as it would very rapidly cool the fuel to below the temperature at which the decomposition can take place, and the action would cease, but if air and steam be blown in together in suitable proportions the combustion of the carbon by air will evolve enough heat to make up for the absorption of heat by the decomposition of steam.

As 12 lb. of carbon burning to carbon-monoxide will evolve 28800 C.U., it is obvious that if there were no loss of heat, and the temperature of decomposition was once attained, it could be maintained by the combustion of a little over 1 lb. of carbon by air for each 1 lb. burnt by steam.

These conditions are, of course, unattainable. The gas leaves the producer at a high temperature and carries away, therefore, a considerable amount of heat, and there is also loss by radiation, so that in practice about 4 or 5 lb. of carbon must be consumed by air for each 1 lb. consumed by steam. It is easy to calculate what should be

* The calorific power of H burning to form water as determined by experiment is about 34180. This, however, includes the heat evolved by the condensation of the steam to water, whilst in this case the steam and hydrogen are in the gaseous condition all the time. The latent heat of steam is about 537, and as each 1 part of H gives 9 parts of water, this will be 4814, which deducted from 34180 leaves 29366, or in round numbers 29000.

the composition of a gas obtained by the combustion of, say, 1 lb. of carbon by steam to 5 lb. by air. It will be convenient to take 12 parts of carbon as the standard, because 12 grammes of carbon burnt by oxygen will give 22·4 litres of carbon-monoxide and of hydrogen.

12 lb. of carbon burnt by steam gives   ...   22·4 litres hydrogen.
12 lb. of carbon burnt by steam gives   ...   22·4 litres carbon-monoxide.
60 lb. of carbon burnt by air gives   ... 112·0 litres carbon-monoxide.
60 lb. of carbon burnt by air gives   ... 209·2 litres nitrogen.

So that the composition of the gas will be—

		By vol.		By weight.
Hydrogen	...	22·4 =	6·1	·46
Carbon-monoxide	...	134·4 =	36·7	38·91
Nitrogen	...	209·2 =	57·2	60·63
		366·0	100·0	100·00

Owing to its extreme lightness, a large percentage of hydrogen by volume only represents a small proportion by weight. It will be at once seen that the gas obtained by the use of steam is much better than that obtained by air alone. The proportion of combustible gas is increased from 34·7 to 42·8, and of this part is now hydrogen, which has a high calorific power.

The calorific power of the gas is—

Hydrogen   ...   ...   ·0056 × 29000   =   162·4
Carbon-monoxide   ...   ·3891 ×   2400   =   933·8

                                                1096·2

An increase of 253 units, or about 30 per cent.

The loss of heat—that is, the heat evolved in the producer—is also much less.

Since the gas contains 38·91 per cent. of carbon-monoxide, it will contain 38·91 × $\frac{12}{28}$ = 16·7 per cent. of carbon, so that 1 lb. of the gas will contain ·167 lb. of carbon.

·167 lb. of carbon if completely burnt to carbon dioxide
    would give   ...   . ·167 × 8080   =   1349 C. U.
1 lb. of the gas will give ...   .   1096 .

                                              Diff.   255

The loss is, therefore, 255 units, or about 19 per cent.

A gas is thus produced having a much higher heating power, with a much smaller loss of heat in the producer. In practice, a still better gas is obtained by the use of coal in the producer. The coal is distilled by the heat of the ascending gases, and the coal gas passes away with the producer gas, the residual coke being afterwards burnt by the air and steam as described above.

The following analyses of producer gas will give an idea of its general composition : —

	1.	2.	3.	4.
Hydrogen ...	4·40	8·60	14·81	12·13
Methane, etc. ...	—	2·40	1·14	2·00
Carbon-monoxide	25·60	24·40	23·11	26·40
Carbon-dioxide ...	4·30	5·20	4·84	9·16
Nitrogen ...	65·70	59·40	56·10	50·31
Combustible % ...	30·00	35·40	39·06	40·33

The quantity of nitrogen in the gas is a measure of the quantity of air used, since practically all the nitrogen comes from the air. The hydrogen is derived partly from the decomposition of the steam, and partly from the distillation of the coal, as coal gas contains about 50 per cent. of hydrogen. The methane and other hydrocarbons are derived almost entirely from the coal.

It will be noticed that all the samples contain carbon-dioxide, none of which was given in our calculated gases. The presence of carbon-dioxide is very objectionable, and the smaller the quantity, as a rule, the better the gas ; indeed, under ordinary circumstances, the quantity of carbon-dioxide present is an inverse measure of the quality of the gas. The presence of carbon-dioxide is due either to (1) too low a temperature, which is almost always produced by the use of too much steam, or (2) to the column of hot coke being too short to allow of its complete decomposition by the hot carbon. The regulation of the quantity of steam is, therefore, of the utmost importance, and, as a rule, too little steam is better than too much. The best test of the working of a producer is the analysis of the gas produced, and at least the carbon-dioxide should be periodically determined.

The influence of the carbon-dioxide is threefold. (1) The carbon present as carbon-dioxide is present in a non-combustible form, and is therefore useless ; (2) the for-

mation of the carbon-dioxide uses up twice as much oxygen as does the formation of carbon-monoxide, and therefore increases the percentage of nitrogen in the gas; and (3) the formation of carbon-dioxide evolves a large quantity of heat in the producer where it is not needed, which is thus lost.
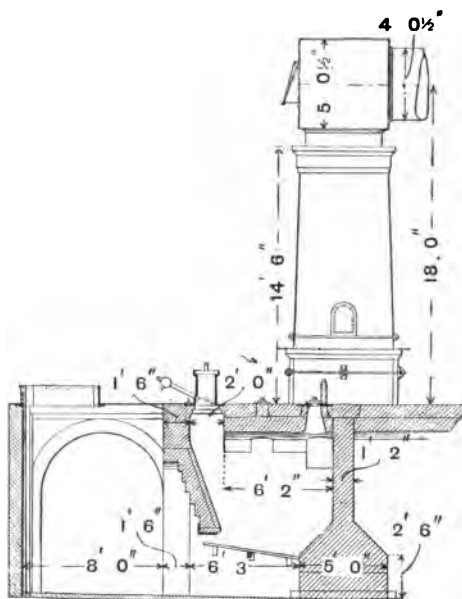
Fig. 25.—Open-type Siemens Gas Producer.

The gas as it passes from a coal-fed producer is always laden with tar. This is carried forward by the gas, and may either be condensed in the mains, or carried forward into the regenerators of the furnace; in either case it is objectionable. The tar may be removed by condensation, or by washing, the removal by the former method being only partial, or it may be destroyed by passing the gas through a column of hot coke, when it is broken up into fixed carbon and permanent gases.

Gas Producers.

The Siemens Producer.—The form of gas producer introduced by Siemens (Fig. 25) was at one time largely used but has now been superseded by more efficient forms. It consisted of a brick chamber or fire-place about 8 ft. square and 8 ft. deep, provided at the bottom with a set of fire-bars. It was provided at the top with a charging opening and a vertical pipe or main, through which the gas was drawn off. When at work it was kept full of fuel, and combustion went on as already described. The air entering through the bars burnt the carbon partly to carbon-dioxide and partly to carbon-monoxide, and the former was to a large extent decomposed as it passed up through the hot fuel. The coal was distilled by the heat of the ascending gases. Steam was supplied by keeping water in the ashpit, and sprinkling water on the bars.

The ash-pit being open, the gas had to be drawn through by means of a natural or chimney draught. If the furnace in which the gas was to be burnt was at a higher level than the producer, the hot gas would naturally find its way upwards. This, however, was very rarely the case, and to provide a draught Siemens designed the overhead cooling tube, which continued in use for a long time.

The producers were placed at a considerable distance from the furnaces. The gas passed into a vertical tube 14 or 15 ft. in height, then through a horizontal tube, and then descended to the furnace by another vertical tube. The gas passing along the horizontal tube was cooled very considerably, so that the gas in the down-comer tube was cooler and, therefore, denser than that in the up-comer tube; as a result, a syphon action was set up, and the gas was drawn over. At the same time, a considerable amount of tar was condensed in the tubes.

With producers with open ash-pits combustion is very slow, not more than 10 lb. of fuel—and often much less—being gasified per square foot of grate per hour. Very little steam can be used, and as the temperature is always low, the gas is usually of poor quality.

Closed Hearth Producers.—The producers now generally used differ from the Siemens in being worked completely

E

closed, the air required for combustion being blown in
with the steam. As, therefore, there is air pressure in the
producer itself, no chimney draught is necessary.

Blowers.—The steam and air are almost always sup-
plied together by means of a steam-jet blower. This
simply consists of a steam jet, about ½ in. in diameter,
supplied with steam at a pressure of from 40 to 70 lb.
per square inch, placed above a tube, about 8 in. in

Fig. 27.—Section of Wilson Gas Producer.

Fig. 26.—Blower for
Producer.
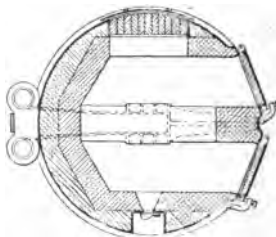
Fig. 28.—Plan of Wilson Gas Producer.

diameter, the upper portion of which is in the form of
an inverted cone, whilst its lower part is slightly conical
(Fig. 26). As the steam rushes from the jet, it carries
with it by friction a considerable quantity of air. The
amount of air carried forward depends on the surface of
the steam jet and on the velocity of the steam, and with
the ordinary solid jet the proportion of steam to air is
usually larger than is necessary. Various other forms of
jet have been devised, such as the annular jet, in which

the steam is blown through an annular opening, so as to form a cylinder of steam, and thus give a much larger surface for a given quantity of steam, and as air may be admitted to the inside of the jet, the surface can be still more largely increased. Some jets are made adjustable, so that the width of the ring of steam and, therefore, the quantity delivered can also be regulated. The ordinary solid jet is, however, still generally used.

The proportions of steam and air used vary. About 6 per cent. of steam by weight is a good proportion. This will give about four parts of carbon burnt by air to each 1 lb. burnt by steam. About 3 lb. of steam will be required for each 1 lb. of carbon consumed, and it must be remembered that it is only the fixed carbon that is burnt in the producer. The most suitable proportions of steam and air are best determined by analyses of the gas produced.

Closed hearth producers may in general be divided into three groups : —

    (1) Bar-bottom producers.
    (2) Solid-bottom producers.
    (3) Water-bottom producers.

Bar-bottom Producers.—In this type of producer the fuel rests on fire-bars as in the Siemens producer already described, but the hearth is closed, and the air and steam are blown under the fire-bars; indeed, the Siemens producer is readily converted to a closed producer by closing the ash-pit by means of iron doors with apertures for the passage of the air and steam. Bar-bottom producers are now but little used in steel works ; the trouble of keeping the bars clear of ashes is very considerable, the loss of fuel through the bars may also be large, and the rate of combustion is slow.

Solid-bottom Producers.—In producers of this type there are no fire-bars, the fuel rests on the solid bottom of the producer, and the air is usually blown in some little distance above the bottom. The best known and most largely used producer of this type is Wilson's.

The Wilson producer is circular (Figs. 27 and 28), cased with iron and lined with fire-bricks, and has an internal

diameter of from 8 to 14 ft. The bottom of the producer is crossed by a ridge of brickwork, which has openings communicating with the body of the producer, and into this the steam and air are blown. On each side of the air passage there is a cleaning door, and also two narrow doors through which bars can be put for cleaning. At the top of the producer a cone of fire-brick is built down into the body so as to leave an annular space into which the gas passes, and from which it is drawn into the main.
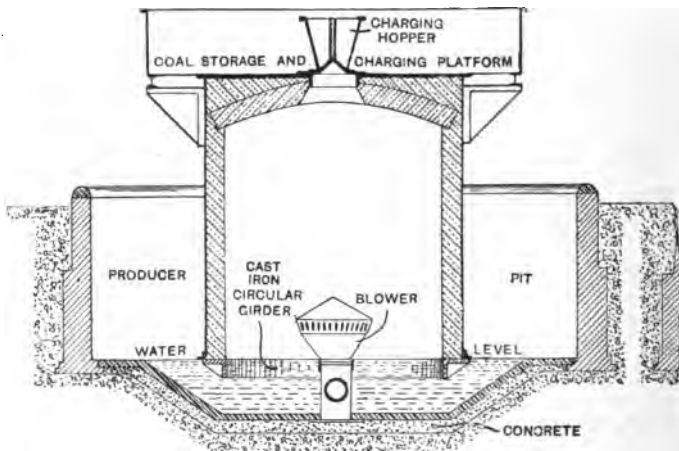
Fig. 29.—Smith & Wincott Producer.

The producer is kept full of fuel to the top, the heat distils the gas and tarry matter, which can only escape by passing downwards through the hot fuel to the annular gas space, and thus the tar is partially broken up. As combustion goes on and the ashes accumulate, the zone of combustion rises, so that the air and steam passing upwards cool the hot ashes and themselves become heated. The ashes must be removed once every 12 or 24 hours. To do this the blast is turned off, the narrow side doors mentioned above are opened, and iron bars are forced through the ashes till they rest on the top of the air channel. The cleaning doors are then opened, and the

ashes are raked out from beneath the bars; the cleaning doors are then closed, the bars are withdrawn, and the charge sinks down; the side doors are closed, and the blast is again put on.

The consumption of fuel on a solid-bottom producer is usually about 20 lb. per square foot of bottom per hour, so that an 8-ft. producer will gasify about 500 lb. of fuel per hour, though the amount may be increased to about double this by giving plenty of air and steam.

The only objection to solid-bottom producers is the necessity for stopping periodically to remove the ashes.

Water-bottom Producers.—In producers of this type the bottom is made in the form of a shallow dish, which is kept full of water; the shell of the producer is made to dip into the water far enough to form a water seal, and from beneath this the ashes are drawn. The ashes are thus thoroughly cooled, the waste heat being utilised in converting some of the water into steam, and the ashes can be drawn out periodically, so that there is no need to stop the producer.

There are a very large number of water-bottom producers in use, those of Messrs. Dawson & Duff being probably the best known. The one described on p. 68 as a type, is that of Messrs. Smith & Wincott, of Glasgow.

The producer (Fig. 29) is about 8 ft. in diameter, cased in iron, the casing dipping into the water-trough so as to form a seal as usual, and being carried on a series of short iron columns. The mixture of air and steam is supplied from below by a central pipe, which widens out in the form of an inverted cone to about 2 ft. 6 in. in diameter, and is then covered with a hood. In the inverted cone are a number of slits by which the air and steam pass into the producer. Owing to the form of the "burner," the holes cannot possibly become stopped up, even with coal which cakes, or which has an ash that clinkers, and the large diameter ensures uniform combustion. The gasifying power of a water-bottom producer is about the same as that of a solid-bottom producer.

The Gas Plant.—Opinions have differed as to whether the gas should be supplied to the furnace hot, or whether it should be first cooled. Siemens contended that a cool

gas was best, and therefore put his producers at some distance from the furnaces, and used the overhead cooling tube. In most modern plants the producers are put as near to the furnaces as they conveniently can be, and underground flues are used, or if for any reason an overhead tube is preferred, it is lined with about 5 in. of fire-brick so as to minimise the loss of heat. The principal difficulty in the use of hot gas is the rapid destruction of the valves. This is overcome by the use of water-cooled valves.

Amount of Fuel Required.—The amount of fuel required for a steel furnace will be roughly about 700 lb. for each ton of steel made. So that if a 25-ton charge is worked in 12 hours, the total fuel required will be about 17,500 lb., or about 1,400-1,500 lb. per hour. Assuming the producer to be circular and 8 ft. in diameter, the area of bottom will be $16 \times 3·1416 = 50·20$, say 50 square ft., and if the gasification be 20 lb. per square ft. per hour, this will give about 1,000 lb. per hour. So that about $1\frac{1}{2}$ producers will be required for each 25 tons of steel made in 12 hours.

These figures are, of course, nothing more than the roughest approximations, and are only intended to give the student some idea of the size of the plant required.

By-product Recovery.—Coal contains a certain percentage varying from a mere trace up to about 1·5 per cent. of nitrogen, and when the coal is distilled, a part, usually rather less than 16 per cent. of this nitrogen, comes off in the form of ammonia. To recover this ammonia, and also the tar, which may be of some value, the gas is sometimes washed before it is burnt. This washing has the further advantage that it removes all the dirt and dust, so that a clean gas is sent forward to the regenerators. The washed gas has, owing to the removal of the tar, a lower calorific power than the unwashed gas. At present, recovery has only been applied to a very small extent in steel works.

Mond Gas.—When a large excess of steam is blown through the producer it cools it, but if air be supplied at the same time it does not completely stop combustion. Owing to the lowering of the temperature carbon-dioxide is to a large extent produced in place of carbon-monoxide, but at the same time a large amount of steam is decomposed, so that the gas contains a large quantity of hydrogen, and though quite different in composition, it has about

the same calorific power, as ordinary producer gas. As remarked above, when coal is distilled, a portion of the nitrogen escapes as ammonia; and from an ordinary coal containing 1·4 per cent. or thereabouts of nitrogen, 23
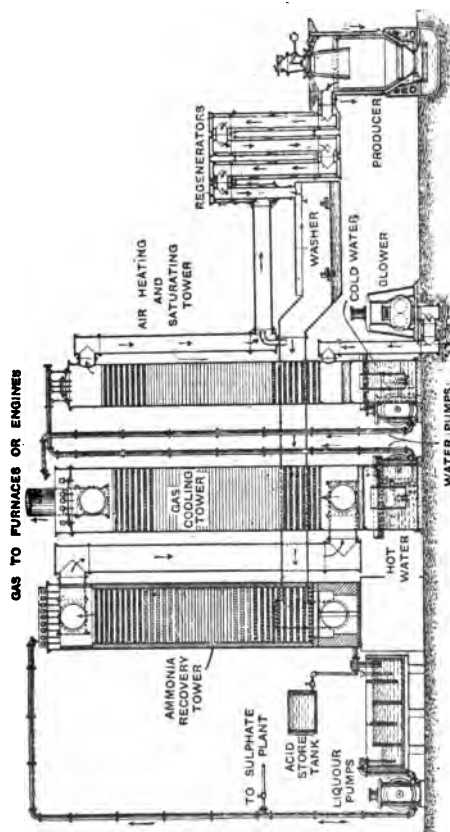

Fig. 30.—Mond Gas Plant.

to 25 lb. of ammonium sulphate can be obtained from each ton of coal consumed. When a large excess of steam is used, the amount of ammonia obtained is much larger, reaching 100 lb. or more of sulphate for each ton of coal.

In Dr. Mond's process, gas is made with the use of a large excess of steam, and the ammonia is recovered. Mond gas, as the gas prepared in this way is called, is gradually coming into use, and in the future may largely take the place of ordinary producer gas for large installations.

The Plant.—The necessary plant consists of a gas producer, and the apparatus for cooling the gas and condensing the ammonia and to some extent the tar, the latter being the essential part of the apparatus, since any form of producer may be used.

The Mond producer (Fig. 30) is a water-bottom producer, the principal peculiarity being that it has a double casing so that the steam and air passing through the space between them on their way to the interior of the producer become heated.

The condensing plant consists of three portions : the regenerators, the washers, and the towers.

The regenerators are a series of double wrought-iron tubes united alternately at top and bottom ; the hot gas from the producer passes through the inner tube, and the steam and air to supply the producer pass through the annular space between the two tubes, travelling in an opposite direction to the gas, so that the mixture is heated by the cooling gas.

The washer, to which the gas next passes, is a large iron chamber partly filled with water, and provided with mechanical dashers by which the water is thrown up in the form of spray, and thus washes the gas as it passes through the chamber above the surface of the water, and cools it to about 90° C.

The gas from the washer first passes to the acid tower, entering at the bottom and passing upwards. As it rises it meets a descending shower of sulphuric acid, which, coming in contact with the ammonia, at once converts it into sulphate. To give a large surface of contact, the tower is filled with a checkerwork of fire-bricks over which the acid runs. The acid liquor contains about 4 per cent. of acid, and is circulated by means of pumps, sulphate liquor being continuously withdrawn and replaced by fresh acid so as to maintain its strength.

The gas, now deprived of its ammonia, passes into a

second tower, which is packed with wood so as to give a large surface, and here it meets a shower of cold water by which it is cooled, and thus largely deprived of its moisture, and is then passed on by mains to the furnaces where it is to be used. .

The water from this cooling tower, which will be warm, is pumped to the top of another tower and allowed to fall ; it there meets the current of air which is being passed forward to supply the producers, which is thus warmed and saturated with moisture.

The amount of steam used is about 2½ tons for each ton of fuel consumed. As a ton of carbon could only decompose 1¼ tons of water, and as the fuel will probably not contain more than 60 or 70 per cent. of carbon, and air is also blown in, a large proportion of this steam, probably about 2 tons, must pass through the producer undecomposed.

The gas produced is very unlike producer gas in composition. It is much lower in carbon-monoxide, and higher in carbon-dioxide and in hydrogen.

The following may be taken as representing the composition of an average sample of the gas :—

			By volume.	By weight.
Carbon-monoxide	...	...	11·0	13·1
Carbon-dioxide...	...	...	17·1	32·0
Marsh gas	...	...	...	1·8	1·2
Olefines	...	...	...	·4	·5
Hydrogen	...	...	...	27·2	2·2
Nitrogen	...	...	...	42·5	51·0
			100·0	100·0

The calorific power of such gas will be about 1,152 C.U., 1,000 cubic ft. weighs about 65-68 lb., and gives, therefore 75,633 Centigrade units of heat (136,193 B.Th.U.). The loss of heat in the producer is about 20 per cent., so that the heating power of the gas is about 80 per cent. of that of the fuel used. The gas is free from tar and ammonia, and burns with a non-luminous flame.

The ammonia recovered amounts to 90 to 100 lb. of sulphate for each ton of coal consumed.

The Siemens Regenerative Furnace.

Principle.—The fuel used is gas, and this, for conveni-
ence and in order to secure uniform heating, is introduced
together with the air alternately at each end of the fur-
nace, and the gas and air are heated to a high tempera-
ture before combustion by passing through regenerators
or chambers filled with fire-brick which have been previ-
ously heated to a high temperature by the products of
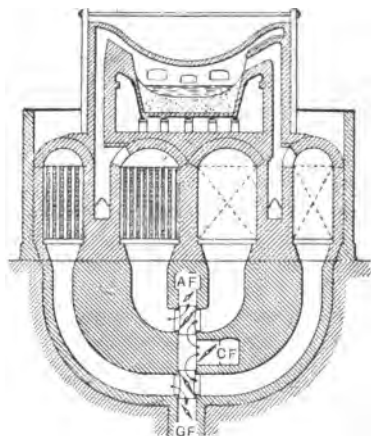combustion.

Fig. 31.—Diagram of Siemens Furnace.—**AF** = Air flue,
GF = Gas flue, **CF** = Chimney flue.

The general arrangement will be seen from the diagram,
Fig. 31. The furnace body is usually placed above the
regenerators. There are four regenerators, two of which
can be put in connection with the air supply and two with
the gas supply, whilst all four can be put in connection
with the chimney, and when the furnace is at work the
pair at one end are always connected with the air and
gas mains and the pair at the other with the chimney. In
the diagram, for clearness, the flues and valves are shown
as being underground; in reality, as shown in the illus-
trations (Figs. 32 and 33), they are in front of the furnace.

The valves being as shown in the sketch, the air and
gas enter the left-hand chambers, pass upwards, and burn
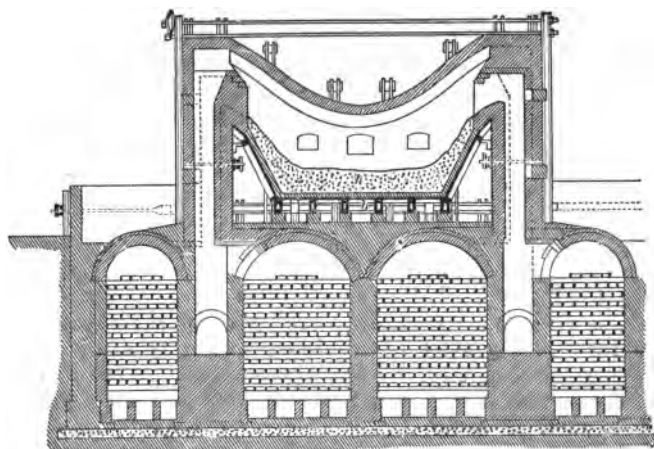
Fig. 32.—Siemens Open-hearth Steel-melting Furnace,
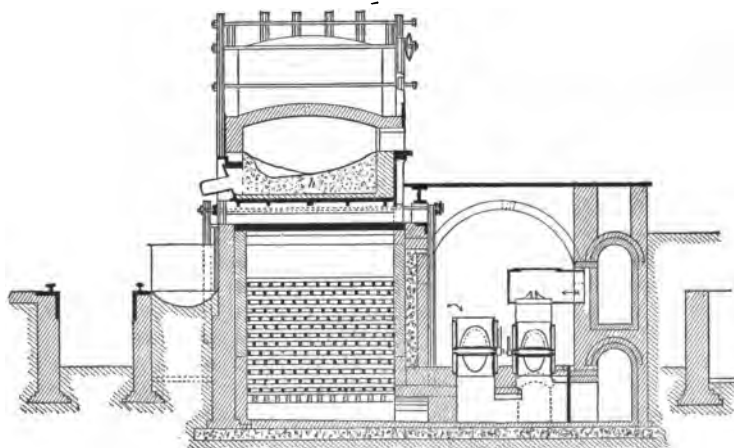Longitudinal Section.

Fg. 33.—Siemens Steel-melting Furnace, Cross Section.

in the furnace; the products of combustion pass along the furnace, down and away to the chimney through the right-hand chambers, which thus become intensely heated. After a time the current is reversed, the air and gas being passed to the furnace through the right-hand chambers, and the products of combustion passing away to the chimney by those at the left-hand. When the furnace is at work the direction is usually reversed every half hour or thereabouts.

The regenerative furnace may be used for very many purposes; indeed, when it was designed, Siemens had no thought of the steel furnace that at present bears his name, and the first furnaces were used for glass-making, then for melting steel in crucibles, and only after some time for melting steel on the open hearth. The details of the furnaces given here, however, will be those applicable to steel melting.

There are three essential parts of the furnace which must be considered somewhat in detail, viz. :—

(1.) The furnace body.
(2.) The regenerative chambers.
(3.) The valves.

The Furnace Body.—The body of the furnace is built of silica brick or other very refractory fire-brick, as shown in Figs. 32 and 33. The roof is also built of silica brick, and is an arch thrown from side to side. As this produces an outward thrust on the walls, these are cased with iron plates and are strongly bound with cross and longitudinal ties, and as the arch expands when it is heated these ties are always arranged so that they can be tightened or loosened as required by means of nuts, wedges, or otherwise. In the older furnaces the roof was usually made to dip considerably from the ends towards the middle, but in modern furnaces it is usually nearly horizontal over the furnace bed, but rises sharply at the ports. The bottom of the furnace consists of a series of strong iron or steel plates carried on cross girders. On this is usually laid a layer of fire-brick set in clay, and above that is the working bottom of refractory sand, which is made to slope towards a tap-hole in the middle of the back of the furnace, the making of which will be described later. The end walls of the furnace are so built as not to throw any weight

on the walls of the regenerative chambers. They may be carried on the walls between the chambers or on strong iron girders. At each end of the furnace are the ports or openings for the admission of air. The gas ports, which are placed below, are two or three rectangular openings splayed outwards so that the gas may spread, and the air ports, which are placed as near the roof as possible, are either a series of similar openings placed above the gas ports, so as to break joint, or more usually now one long narrow opening extending across the whole width of the furnace and overlapping the gas ports at both sides. The ports are usually given a strong downward slope to deflect the air and gas downwards. The flues connecting with the regenerators are carried up in masonry stacks outside the furnace.

The whole of the material of the furnace must be very refractory, and silica bricks (Dinas or other), which consist of silica fritted together by the addition of a small quantity of lime or other basic material, are always used.

The furnace is provided with door openings, usually three on each side. If the charge is to be pig iron and small scrap, these doors are about 2 ft. 6 in. long by 1 ft. 6 in. to 2 ft. high, but if large scrap has to be introduced, one at least at the back* of the furnace will be made much larger. In front of each door opening is a projecting ledge, and on this rests the door, an iron frame filled with fire-brick. This is hung by a chain to a lever, so that it can be easily raised or lowered as required.

The size of the furnace varies very much. The early furnaces had a capacity of 5 or 6 tons, and were about 10 or 12 ft. long and 7 or 8 ft. wide. The capacity of the furnaces has now been much increased; 50-ton furnaces are common, and much larger ones have been erected. The length may be up to 40 ft., and the width up to 15 or 16 ft., but there is no general agreement as to the most economical size or the best proportions. On the whole, furnaces having a capacity of about 50 tons seem to be the most popular.

As the furnace is usually above the regenerators, it

* The terms back and front are used somewhat vaguely in connection with steel furnaces. In this book the tapping side is called the front, and the charging side the back.

will be at a considerable elevation, and, indeed, this is necessary to allow of the tapping of the metal into the ladle.

The Regenerative Chambers.—These, as already re-marked, are usually placed under the furnace, and are four in number. The size varies very much, the tendency of late having been towards the use of very large chambers. As the object of the chambers is to intercept as much of the waste heat of the products of combustion as possible and then to restore it to the incoming gas and air, it is obvious that within limits a large chamber will be more efficient than a small one. The length of the chamber is in general determined by the width of the furnace; its width can be varied within wide limits, but it is not desirable to carry the chambers too far beyond the ends of the furnace. The depth can be varied considerably, but, as the draught depends on a chimney, too deep a regenerator might interfere with this, and at the same time there are often practical difficulties in the way of constructing very deep chambers, especially in low-lying districts in the neighbourhood of rivers. The chambers are now usually from 12 to 20 ft. deep, or in some cases even deeper, 12 to 20 ft. long, and 6 to 10 ft. wide, but it is obvious that the larger the furnaces the larger will the chambers need to be.

Siemens stated that 17 lbs. of regenerator fire-brick at each end of the furnace per pound of coal burnt in the producer per hour would be theoretically sufficient to absorb the waste heat of the products of combustion, but it must be remembered that the brickwork is by no means uniformly heated, the top becoming much hotter than the bottom, so that three or four times as much brickwork will be required. The spaces between the bricks must be such as to allow a free passage of the gas, and a surface of at least 6 sq. ft. is necessary for each pound of coal consumed per hour.

As a rule, the two inner regenerators are used for the air and the outer ones for the gas, but there is little real reason why this should be so; and, as a rule, the air regenerators are made from 5 to 25 per cent. wider (the other dimensions being the same) than those for the gas. An ordinary producer gas requires about its

own volume of air (under the same conditions of temperature and pressure) for complete combustion, and there is no general rule as to the relative sizes of the chambers.

The chequers must be very refractory, but owing to the large amount of dust carried forward, which attacks silica, silica bricks are not the best suited for the purpose, refractory clay bricks being better.

The Valves.—The valves by which the direction of the air, gas, and products of combustion is regulated are, of the utmost importance. They must be easily reversed, quite air-tight, and should be very durable. Very many forms
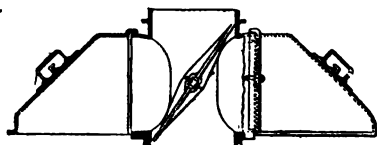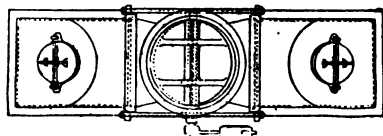

Fig. 34.

Fig. 35.

Figs. 34 and 35.—Section and Plan of Valve Box for Siemens Furnace.

of valves, water-cooled and other, have been introduced, but the butterfly valve used by Siemens still continues in general use, because it is cheap and easily replaced.

The valve (Figs. 34 and 35) consists of a cast-iron plate strengthened by ribs cast on it, and fixed in a suitable valve box with carefully machined valve seats, as shown in Fig. 34. It will be seen at once that by simply turning over the valve on its axis the direction of the air or gas current can be reversed. As the chimney gas on one side of the valve will be hot, and the air or gas on the other side is cold, and the sides are alternated very frequently, the valve is very apt to warp, and thus to leak, the chimney draught drawing the air or gas direct to the chimney instead of allowing it to pass through the regenerators, thus entailing considerable loss. In the case

of the gas valve, the gas may burn in the excess of air in the products of combustion, and the heat thus evolved will help to destroy the valve.   As soon as a valve is found to leak it is replaced.

There are, of course, two sets of valves, one for the air and one for the gas, the former opening direct to the air and the latter communicating with the gas main.   An additional valve, usually a crown valve, is also provided

Fig. 36.—View of Front or Casting Platform of Siemens Furnaces.

for the gas main, by which the supply of gas can be regulated and cut off when it is necessary to change the valve, and the opening of the air pipe has a cover which can be partially closed so as to regulate the air supply.

Arrangement of the Furnaces.—As stated above, the furnace, being above the regenerators, will be at a considerable elevation.   At the back or working side of the furnace is a broad platform, from which the furnace is charged and on which the materials to be used are placed. This platform should be at least 20 ft. wide, and the wider

the better, and the trucks conveying the material for use should be brought up to it.

Near each furnace will be the handles for reversing the

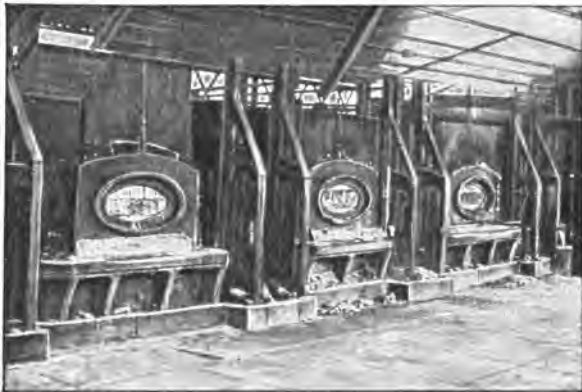Fig. 37.—Front or Casting Side of Siemens Furnace, showing Gallery

Fig. 38.—View of Back or Working Platform of Siemens Furnace.

valves and controlling the gas supply, and the valve boxes are usually in a passage which runs beneath the platform. Figs. 36 to 38 show three views of a Siemens furnace.

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On the platform also are two small furnaces, one for
heating the ferro-manganese, which is to be used for
recarburising, and the other for heating the sand to be
used for repairing the bottom after each charge. There is
also a trough of water, the "water bosh," in which the
tools are cooled after use. At the front or casting side of
the furnace the floor level must be low enough to allow
the ladle which is to receive the charge to be run under the
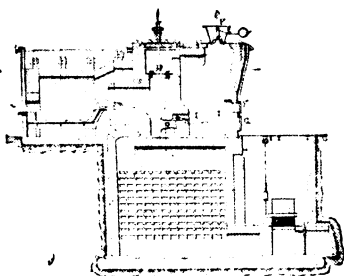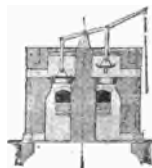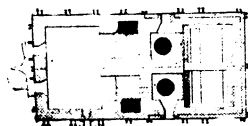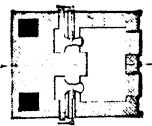
Fig. 39.—Side Section of Siemens New Form Furnace. Fig. 40.—
Plan of Siemens New Form Furnace. Fig. 41.—End Section of
Siemens New Form Furnace. Fig. 42.—End Plan of Siemens
New Form Furnace. Fig. 43.—Side Section of Siemens New
Form Furnace.

tap-hole of the furnace. At the same level as the back
platform a narrow gallery runs along the front of the fur-
nace so that access can be had to the doors on that side.
This gallery is divided opposite the tap-hole, and there
a shoot is arranged by which the metal flows into the
ladle. The shoot is usually supported on an axis, so that
as soon as the steel is all in the ladle it can be turned up.

Siemens New Form Furnace.—This furnace (Figs. 39
to 43), which was invented by Mr. F. Siemens, differs in
some important respects from the ordinary type of furnace.

It has not been used on a large scale for steel melting, but several small experimental furnaces have been built, and it has been largely used for heating furnaces.

There are only two regenerators, those for air; the gas producer is attached to the furnace so as to be part of it, and part of the hot products of combustion are passed through the producer, the other part being passed through the regenerators as usual. The gas enters and leaves the furnace at the same side, sweeping round in a curve from the one set of ports to the other, so that in the case of long furnaces the producers, and therefore the gas supply, are at the side. The producer is provided with two sets of ports communicating with the furnace, which are used alternately.

The products of combustion will have approximately the composition

Carbon-dioxide	...	...	17 per cent.
Oxygen	...	...	2 „
Nitrogen	...	...	81 „

though the quantity of oxygen may be much larger, and there will also be a considerable quantity of steam. When this is passed over hot fuel the carbon-dioxide will be reduced to carbon-monoxide, and the steam will be decomposed, yielding hydrogen and carbon-monoxide. Thus the products of combustion will be regenerated so as to yield a combustible gas, and in the process heat will be absorbed. Some air will also be sent in to the producer. The results of the combustion of the carbon and of the high temperature at which the waste gases enter the producer are that the gas enters the furnace at as high a temperature as would be produced if regenerators were used.

Gas from the producer passes through one flue to the gas port, and thence into the combustion chamber. Air passes through the regenerator by an air flue and the air port into the combustion chamber, where it meets the gas, and combustion takes place. The flame sweeps round the hearth, and the products of combustion pass away by the other port, and go partly through the gas producer and partly through the regenerator.

CHAPTER VI.

Principle.—When a mass of pig iron is kept melted and the surface is exposed to the air, oxidation goes on. A layer of slag is formed and the oxidation continues, indirectly owing to the oxidising action of the slag, which contains a large quantity of oxide of iron, and ultimately, if the quantity of metal be small, all the carbon and silicon will be removed. This is exactly what takes place in the process of puddling, which was fully described in the volume on "Iron" in this series. In puddling, the temperature being comparatively low, the carbon-free iron does not melt, but remains in a pasty condition. With the regenerative furnace the temperature is much higher, and, therefore, the metal remains liquid to the end. When, however, larger quantities of iron are melted—tons instead of hundredweights—the action of atmospheric oxidation becomes so slow that complete decarburisation by its influence would be impracticable, but by the addition of oxide of iron, in the form of hæmatite, or of any other form of oxide that is available, the process can be made much more rapid. In the Siemens process, the pig iron is melted, and the impurities are burnt out by the addition of oxide of iron; and when all the carbon has been removed, the amount required for the steel is added, and any dissolved oxygen is removed by the addition of ferro-manganese, exactly as in the Bessemer process.

The Process.—The charge having been tapped out, the bottom of the furnace is carefully examined, and if there are any holes, these are made up with sand, and then the furnace is ready for charging. The pig iron' and scrap which are to be used will have been piled up on the platform so as to be ready for charging. One man takes his place at each of the three doors at the back of the furnace, and is provided with a flat paddle with a long handle, which he rests on the sill of the door. Other men bring up

the pig iron, and as each pig is placed on the paddle the man pushes it into the furnace, tilts it so as to drop the pig very gently on to the bottom of the furnace, and then withdraws it so as to receive the next pig, and so on till all the iron is in. If scrap is being used, it will, if in pieces of convenient size, be charged exactly in the same way as the pig, but if small it will be thrown in by means of shovels. If the pig and scrap be at some distance from the furnace, it may take two men to carry for each charger. The time occupied in charging a 50-ton furnace will be two or three hours, and may be longer if the scrap is small. In charging the pig iron is put on the bottom of the furnace, and the scrap on the top of it.

As soon as the charge is in the doors are closed, and the gas is put full on. The pig iron soon melts and dissolves the scrap. As melting is going on a large surface is exposed to the air, so that there is a considerable amount of oxidation, and oxide of iron formed combines with the silica of the sand adherent to the pigs, perhaps some of the silica of the furnace lining, and that produced by the oxidation of the silicon in the iron, to form a slag which is sufficient to cover the surface of the metal when it is melted. The melting-down stage will occupy three or four hours, so that in five or six hours from the time charging was commenced the whole will be liquid.

The doors are now opened and the iron ore is thrown in a shovelful at a time, and is thoroughly mixed in with the molten metal. At first there is no visible change, but the slag increases in quantity ; and after a time the metal begins to boil, that is, gas escapes and forms bubbles at the surface exactly as in the boil during puddling. The workmen still continue to add the ore and stir it in, and after a time the boil subsides and the working of the charge is complete. Samples are now taken, cast into small ingots, flattened, and broken; and a sample is sent to the laboratory which is always close at hand, usually on the working platform, and the carbon is rapidly determined colorometrically. If it is not sufficiently low the "oreing" is resumed for a short time, and then another sample is taken, and when the carbon is reduced to the necessary amount, the charge is ready for tapping.

The tap hole is opened by forcing a steel crowbar

into it by means of a sledge-hammer, and the metal flows into the ladle, enough slag being allowed to follow it to form a cover to the metal ; then the shoot is turned up, and the rest of the slag flows on to the ground, to be afterwards removed and carried to the slag tip, and the steel is at once distributed to the moulds.

The ferro-manganese, usually hot, is thrown into the ladle as the metal flows from the furnace.

The time occupied will vary from 10 to 16 hours or thereabouts, depending mainly on the quantity of silicon and carbon that has to be oxidised out. The more scrap is added the more the carbon and silicon will be diluted, and the less time will the working of the charge take. There is no absolute necessity for the use of scrap, but an all-pig charge would take longer to work, and so much scrap. is produced during the working of the steel that there is usually a large quantity to be used up, or it can be purchased at a reasonable rate for remelting .from the large engineering shops where mild steel is used.

Chemistry of the Process.—The chemistry of the process is very simple ; indeed, it is almost exactly the same as that of the puddling process which has been described in the companion volume on " Iron."

During the charging oxidation begins, the pig iron being exposed to the oxidising atmosphere of the furnace. During melting down the flame is kept oxidising, so that oxidation still further continues, and by the time the whole is melted, a large quantity of oxide of iron has been formed, which attacks the silicon in the iron, and forms ferrous silicate which floats on the metal as a slag.

The following figures will indicate the way in which the impurities are removed :—

	Charge.	When melted.	Beginning of boil.	At end of boil.	Finished steel.
Carbon ...	2·85	2·63	2·50	0·13	0·18
Silicon ...	1·41	0·84	0·36	0·02	0·02
Phosphorus ...	0·048	0·048	0·049	0·049	0·05
Sulphur ...	0·048	0·048	0·049	0·05	0·05
Manganese ...	0·75	0·56	0·11	Tr.	0·54

As the ore is added, the oxidation is still further continued ; thus $Fe_2O_3 + Si = FeO, SiO_2 + Fe$.

Then as soon as the silicon is almost removed, the carbon is attacked, and escapes as carbon-monoxide, $Fe_2O_3 + 3C. = 2Fe + 3CO$.

It will be seen that the silicon is very rapidly removed, so that at the end it is practically completely gone. This is due partly to the fact that owing to the dilution with scrap the amount of silicon is never very high, and, secondly, to the fact that the temperature, being much lower than that of the Bessemer converter, favours the elimination of the silicon. The manganese is also altogether removed, and the carbon can be completely eliminated if the process is pushed to its end. As in the Bessemer process, sulphur and phosphorus are not removed at all.

As the silicon is almost entirely got rid of early in the process, it is not always necessary to oxidise out the whole of the carbon, but if a steel fairly high in carbon is required, the process may be stopped "on the down grade," when the residual metal contains, say, 0·2 or 0·3 per cent. of carbon, and then much less ferro-manganese need be added.

Very much less oxygen is taken up in the Siemens furnace than in the Bessemer converter, and therefore less manganese is necessary, and this amount of oxygen can be reduced by what is called "pigging back," that is, by the addition at the end of the process of one or two half pigs of iron, previously heated. This is not enough to make any difference in the ultimate composition of the metal, but it helps to remove the oxygen. It sometimes happens that the amount of residual oxygen is so small that practically all the manganese added in the ferro-manganese can be accounted for in the resulting steel.

Thermal Reactions.—The heat evolution will be somewhat less than in the Bessemer process, because the oxidation takes place by means of ferric-oxide, the decomposition of which will absorb a certain amount of heat. The heat evolution also is spread over a much longer time, and therefore it is of little practical moment, though undoubtedly it must do something to keep up the temperature of the bath.

Materials.

The Pig Iron.—Pig iron suitable for the Siemens

process should be free from sulphur and phosphorus. The amount of the other constituents is of little importance. No definite amount of silicon is required to evolve heat, but a very large quantity would be objectionable, as it would delay the process, and for the same reason a large percentage of manganese is not good. On the other hand, too little silicon is not advisable, as the metal may oxidise too rapidly and the furnace bottom may be unduly attacked.

The Ore.—The iron ore used should be a hæmatite as free as possible from silica and other impurities. Not only is silica objectionable as reducing the percentage of oxide of iron that can be present, but also it will combine with a further amount of oxide to form silicate, which will pass into the slag. It is also important that the ore should be free from sulphur and phosphorus. The favourite ore, when it can be obtained, is Campanil from Bilbao. This is a hæmatite and the gangue is carbonate of lime, which is not objectionable.

The amount of ore required will vary with the character of the iron being worked.

The Scrap.—Any variety of steel or malleable iron scrap may be used. The more scrap is in the charge the less ore will be required.

The Recarburiser.—Spiegeleisen or ferro-manganese or sometimes silicon-ferro-manganese is used. It is not so important that this be high in manganese as in the Bessemer process, because the amount of oxygen to be removed is less.

The Products.

The Steel.—Steel can be made of any quality, from dead soft, with about ˙10 per cent. of carbon or less, to hard wire rod with about 1˙0 per cent., but as a rule steel is made with less than ˙75 per cent. of carbon. The process is completely under control; samples may be taken and analysed before the steel is finally tapped, so that steel of any required composition can be accurately made.

The Slag.—The slag is a silicate of iron with small quantities of other constituents. It is an acid slag, the quantity of oxide of iron not being sufficient to make it strongly basic in presence of the siliceous lining of the

furnace. It is important that the slag should contain sufficient oxide of iron to bring about the required oxidation. The more basic the slag the better oxidising agent it will be, whilst with a very acid slag not only may there be no oxidation, but manganese and silicon may be reduced from it.

The following analysis of a slag will give an idea of the composition of a good slag :—

Silica	55		Magnesia	2
Ferrous oxide	25		Alumina	1
Ferric oxide	2		Phosphoric acid (P_2O_5)	·05
Manganese oxide ...	10		Sulphuric acid (SO_3) ...	trace
Lime	5			

The amount of slag also must necessarily vary, but will roughly be about 10 to 15 per cent. of the weight of the original charge.

Making a Furnace Bottom.—When a new furnace has been built the bottom has to be very carefully made. The brickwork of the furnace is first of all dried by making up a fire on a temporary grate in the middle of the hearth. When the furnace is dry the bars are removed, the ashes raked out, and the gas put on, and continued till the interior of the furnace is red hot. A layer of a mixture of loam and sand is thrown on the brick bottom, and the heat is continued till this fuses. Then layers of a refractory white sand mixed with a much less refractory sand are thrown in, and as each layer frits another containing more of the strongly refractory sand is added, till at last it is added alone, and the highest attainable temperature is got, which is just enough to frit but not to fuse the sand. A quantity of slag is then added and melted so as to fill up the crevices in the sand, and any residual slag is tapped off. Ten to 20 tons of sand may be required, and the time occupied, including the drying of the furnace, may be 10 or 12 days.

The first charge worked is always a small one, and additional slag-forming materials are added.

An aperture is left in the brickwork for the tap-hole. This is filled up with ganister rammed from inside the furnace before the gas is put on, and later a hole is cut through the mass of ganister for the tap-hole.

Output of Process.—The output of the open-hearth

process falls far below that of the Bessemer process. A 50-ton charge may be completed in about 12 hours, including the time necessary for repairs, so that about 11 charges, or 550 tons, will be obtained in a week.

The process allows considerably more variation in the pig iron used than does the Bessemer process. It is much more under control, so that it is easier to turn out steel of a perfectly definite quality, and probably a milder steel can be made. The loss of iron is also considerably less, 100 tons of pig yielding 95 to 97, or sometimes even over 100, tons of steel. The reason for the large yield is, of course, that some iron is reduced from the ore added, and this to some extent compensates for the loss by oxidation.

The Siemens-Martin Process.—The Siemens furnace was first used in connection with steel-making by M. Martin, of Sireuil. He used it for the remelting of steel scrap, with the addition of a small quantity of pig iron. Siemens had tried to melt steel on the hearth of his furnace, but had failed on account of the oxidation which took place. M. Martin saw that this could be overcome by the addition of pig iron, the silicon and carbon of which could be oxidised out. The process is conducted exactly as the Siemens process, except that a much larger proportion of scrap is used and no ore is added.

The Siemens-Martin or pig and scrap process came largely into use as an adjunct to the Bessemer process for using up the scrap, with which that process could not deal.

The first plant for the carrying out of this process in this country was that erected in 1868 at the Crewe works of the London and North Western Railway.

Whenever ore is used the process is the Siemens, not the Siemens-Martin, since in the latter only pig and scrap are used, and the furnace should always be spoken of as the Siemens, not the Siemens-Martin, and still less the Martin, as is sometimes done in steel works.

CHAPTER VII.

THE BASIC OPEN-HEARTH PROCESS.

WHEN the basic Bessemer process proved a success, steel-makers soon began to ask : Could not the open-hearth process be worked with a basic lining? and, if so, would such a process not have the same advantages over the ordinary open-hearth process that the basic Bessemer has over the acid Bessemer process? Many workers set to work to answer these questions by direct experiment, and, though many and unexpected difficulties were met, these were in time overcome and the process made a success.

The Furnace.—In essentials the furnace used does not differ from that already described, the only difference being that the hearth or bottom is made of some basic material, magnesian lime or burnt magnesite. Basic bricks are not strong enough for furnace building, so that the furnace itself must be built as usual of clay or silica bricks. This introduces the difficulty that the basic material of the bottom must not be allowed to come in contact with the siliceous material of which the furnace is built, or at the high temperature of the furnace they will flux one another. This difficulty has been overcome by the use of a parting layer of some neutral material, which, being neither acted on by the basic material nor by the silica, can be used to separate them.

The neutral material almost always used is chromite or chrome iron ore, which has the formula $FeOCr_2O_3$, but usually contains other elements as impurities. It may be used in the form of bricks or as a powder rammed in where the acid and basic materials would come in contact.

In some cases the furnace, below the level of the hearth, is built of basic material, the upper portion only being of acid bricks, a parting layer of chrome bricks being used to separate the two. The bottom is made much in the same way and of the same materials as the lining of the basic converter. (Fig. 44, Basic Furnace showing Neutral

Parting Layer.) On the iron plates a layer of bricks is laid as usual, either clay or basic bricks being used. On this is rammed in the usual way a thin layer of the dolomitic-tar mixture, and this is heated till it is hard. Then crushed dolomitic 'lime, either alone or mixed with a little tar, is spread over the bottom in thin layers, each being heated till it frits before another is put on, and so on till the hearth is complete. The basic hearth must be carried well above the slag line, as the very basic slag produced in the process would rapidly destroy the silica bricks.
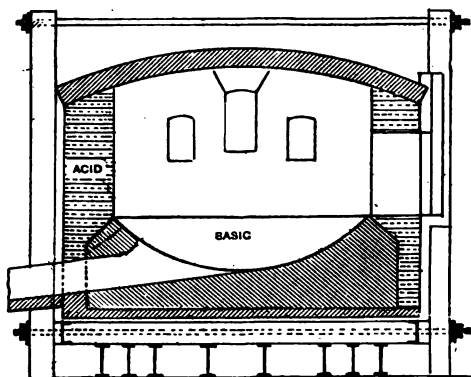

Fig. 44.—Basic Furnace, showing Neutral Parting Layer.

Other materials have been suggested for making the bottom, but none have come largely into use. Calcined magnesite ($MgCO_3$) answers well, but is very costly, and it has the advantage that no parting layer is necessary.

Working a Charge.—The method of working is very similar to that in the acid process, except that lime and often oxide of iron is added with the charge, and lime is added with the ore during the working of the process. The charge is introduced into the furnace in the usual way, the scrap either being added on the top of the pig or introduced after the pig is melted. The oreing is conducted in the usual way, lime being charged in with the ore. As the boil approaches the end, samples are taken in the spoon as usual, hammered down, and broken. When

the fracture indicates that the working is nearly com-
plete, a sample is sent to the laboratory, and the carbon
and phosphorus are rapidly determined, or, rather, the
carbon is determined, and the chemist judges from the
appearance of the precipitate of the phospho-molybdate
whether the phosphorus is low enough, and if not, the
working is continued till a satisfactory test is obtained.
The metal is then tapped out as usual, the slag not being
allowed to run into the ladle, the ferro-manganese being
always added in the ladle when the metal is free from slag.

Chemistry of the Process.—As far as the oxida-
tion of the silicon and carbon is concerned, the action
is exactly the same as in the acid process, there
being first a period of slag formation when the silicon
is being oxidised, and then a " boil " when the carbon
is removed. The removal of the phosphorus is, however,
quite different from that in the basic Bessemer blow. There
is no stage corresponding to the after-blow, the phos-
phorus being removed continuously from the beginning
of the oxidation, and the removal being complete before
the end of the boil, *i.e.* before the carbon is all out;
indeed, should any phosphorus remain after the carbon
is all removed, it is very difficult to get rid of it, and
usually pig iron, free from phosphorus, is added to bring
the metal back to the boil. The phosphorus passes into
the slag as calcium phosphate, and to ensure its removal
the slag must be kept strongly basic, but at the same time
so much lime must not be added as to make it too pasty.
The phosphorus should be reduced to about ·05 per cent.
before the metal is tapped.

The following figures will indicate the way in which
the impurities are removed.

	Charge.	After fusion.	Coming to boil.	Ready for tapping.	Steel in ladle.
Carbon ...	2·23	·71	·34	·12	·16
Silicon ...	·43	·06	·01	·01	·01
Manganese ...	·84	·33	·25	·22	·49
Phosphorus ...	·203	·046	·022	·013	·018

The reason for the difference in the removal of the
phosphorus in the basic open-hearth and basic Bessemer
processes is that the temperature is much lower in the

former, and the low temperature seems to facilitate the slagging of the phosphorus. Sulphur is only removed to a very small extent.

Materials.

The Pig Iron.—A very wide range of iron is available for the basic open-hearth process. As the heat of oxidation is not required, no large amount of phosphorus is necessary, but an iron with much or little can be worked. If the phosphorus is very high, it is, however, well to use a good deal of scrap to dilute the charge. The silicon is unimportant, but should be kept low, as a high silicon causes waste of lime, and may prolong the working. The manganese should not be high, as it is not rapidly removed, owing to the basic character of the slag. As sulphur is not removed the pig must be free from this constituent.

A typical pig suitable for the process would contain—

Carbon	...	...	3·5	Manganese	...	...	1 0
Silicon	...	...	1 5	Sulphur	...	...	·05
Phosphorus	...	...	1·0			

but, as remarked above, all the consituents may vary within very wide limits; indeed, it may be said that any pig iron not containing sulphur can be worked on the basic open-hearth furnace.

Scrap.—Scrap of any kind may be used.

Ore.—A good hæmatite should be used, as free as possible from silica, but freedom from phosphorus is not essential as it is with the acid process.

Lime.—The lime used should be as free as possible from silica; it should be freshly burnt.

The Products.

The Steel.—The steel does not differ from that made by other processes; with care the phosphorus can be kept down to an amount not at all in excess of that found in steel made by the acid process. A milder steel can be made on the basic open-hearth furnace than by any other process, because the carbon in the charge can be completely eliminated, and as very little oxygen will have been taken up, only a small addition of ferro-manganese

will be required. Steel made in the basic open-hearth furnace is the nearest approach to pure iron that has yet been obtained commercially. It is not easy to make a steel high in carbon, because the process must be continued till all the carbon is out to ensure the removal of the phosphorus, and the addition of a large quantity of ferromanganese would, of course, introduce too much of other impurities. The Darby process of recarburising (see p. 108) was introduced to overcome this difficulty.

The Slag.—The slag is a silicate of iron and lime containing also phosphate of lime. The silica must be kept low to ensure the removal of the phosphorus, so that the amount of lime to be added will vary directly with the amount of silicon in the iron. As the slag must be kept sufficiently liquid and sufficiently oxidising during the process, the ore and lime must be added from time to time as the oxidation goes on. The slag at the end should not contain more than about 12 per cent. of silica and 16 or 17 per cent. of oxide of iron, and about 40 per cent. of lime. The amount of phosphoric acid will depend on the amount of phosphorus in the iron. ·

When working iron high in phosphorus and low in silicon, the slag will contain enough phosphorus to be of value as a manure, but in other cases it will not.

Future of the Process.—The basic open-hearth process will probably be very largely used in the future, as the wide range of pig available gives it a general applicability which none of the other processes have. It is more costly to work than the acid process on account of the large quantity of lime used, and also because the furnace needs more constant repair. The time occupied is about the same as that of the acid process, and depends on the amount of impurities to be removed.

Removal of Sulphur.—Sulphur is the one element not removed by any of the steel processes described, so that in all cases a sulphur-free iron must be used.

Mr. Ernest Henry Saniter devised a process for the desulphurisation of pig iron, depending on the use of lime and calcium chloride. This can be used on the pig iron as it flows from the blast furnace, and, therefore, a sulphur-free iron can be obtained from ores and other materials containing sulphur.

Mr. Saniter has also applied his process to the desulphurisation in the open-hearth furnace, so that good steel can be made from iron containing a fair proportion of sulphur. A large amount of lime must be added so as to produce a slag containing at least 50 per cent. of lime, and with the latter portions of the lime dry calcium chloride or a mixture of calcium chloride and fluorspar is also added, and the charge worked as usual, the sulphur then passing into the slag. The reaction takes longer than when there is no sulphur to be removed. The chemical action is somewhat uncertain. The lime seems to be the active desulphurising agent, and the action of the calcium chloride or fluorspar may be only to keep the very basic slag sufficiently liquid to allow it to act upon the metal. The removal of the sulphur is fairly complete, a steel not less than ·03 per cent. having been made from iron with over ·5 per cent.

The calcium chloride or fluorspar seems to reduce the solubility of the phosphate, and thus diminish the value of the slag for manure.

CHAPTER VIII.

MODIFICATIONS OF THE OPEN-HEARTH PROCESSES.

DURING the last few years a vast amount of attention has been given to the open-hearth steel processes, and many modifications, both in plant and method of working, have been suggested, mainly with the object of increasing the output of the furnaces or diminishing the amount of labour. Almost every part of the plant has been modified in various ways, but it will not be necessary here to deal with minor inventions and improvements.

Charging.—One of the most tedious operations in connection with the open-hearth furnace is the charging. The charging of a 25-ton furnace by hand takes about two hours, and with larger furnaces proportionately longer, and it is impossible to shorten the time by increasing the amount of labour, as there is not room for more men to work.

To overcome this, two methods have been suggested : (1) the use of liquid metal; (2) charging machines.

(1.) *Liquid Metal.*—This method is only applicable where the metal can be taken from the blast furnace either direct or through a mixer, for it would certainly not pay to melt the iron in a cupola as is done in the Bessemer process. The metal from the furnace or the mixer is run into a large ladle, this is taken to the furnace, and the metal run into the furnace by means of a shoot, either by tapping the ladle or by tilting it and pouring out the metal, the latter being the more usual and most satisfactory plan. In some works an overhead crane runs along the whole length of the furnaces over the working platform, and by this the ladle is lifted from the carriage by which it is brought from the mixer, carried to the furnace, and then, by means of a chain attached to the bottom of the ladle, the metal is poured into the furnace.

This method saves labour at the pig bed and in charging the furnace, but it does not materially shorten the

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process, and more ore is required in working. The reason for this is that in the ordinary process there is a good deal of oxidation whilst the metal is melting, a large surface being exposed to the air, and this, of course, does
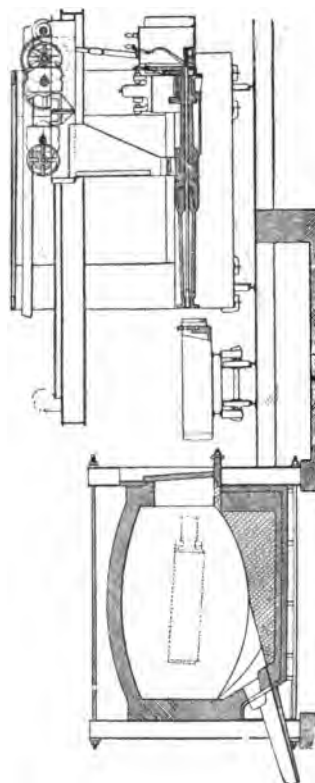

Fig. 45.—Section of Wellman Charging Machine.

not take place when the metal is poured into the furnace, but oreing must be begun at once.

Charging Machines — Several forms of charging machines have been devised, but the only one that has come largely into use is the Wellman (Figs. 45 and 46),

made by the Wellman-Seaver-Morgan Company, so it will be sufficient to describe that.

The charging platform must be broad and the roof lofty, and the furnaces should be in a single line. The charger is made in two forms, one carried on a carriage

Fig. 46.—View of Wellman Charging Machine.

Fig. 47.—Wellman-Seaver Electric Overhead Charger.

which runs on rails on the platform, the other which is carried overhead (Fig. 47). The latter form will be described here.

Along the front of the furnaces is laid a narrow rail track, on which the trucks carrying the charge can run. The charger itself is carried on strong girders running

the whole length of the melting shop in front of the
furnace, and is like a strong overhead crane, carrying
motors by which motion can be given in two directions,
viz. the whole framework along the furnaces, and the
charger truck itself to and from the furnaces. From the
charger truck descends to about the level of the furnace
door a strong framework, which carries the charging bars
and the operator's platform. The charging platform is at-
tached to the charging bar and carries a small motor
by which the bar can be turned right or left, up or down,
and another by which it can be rotated on its axis. As
the charger's platform is at the end of the bar, the charger
can always see along the whole length of it.

The charge is put into a series of charging boxes, 6 ft.
long by 2 ft. wide and 1 ft. 9 in. deep, each of which will
hold about 1 ton of scrap or pig iron. These are placed
on bogies and are drawn into position in front of the
furnace.

At the end of each charging box is a socket into which
the end of the charging bar is made to fit. The charging
bar itself is hollow, and through it runs a strong rod, the
locking bar for holding the boxes in position. Driving
the locking bar forward against the end of the box fixes
it, and withdrawing it releases it.

The charged boxes being in front of the furnace, the
charger is brought up, the end of the bar is lowered into
the socket on the charging box so as to hold it securely,
and by lifting the bar the box is lifted off the carriage.
The charger truck is now advanced towards the furnace,
so that the box is pushed through the door into the fur-
nace. The man on the platform, by turning the bar to the
right or to the left, gets the box into the required position,
then rotates the bar so as to turn it over, depositing the
charge on the hearth of the furnace. The box is then
turned up again, the truck run back, so that the box
is drawn out of the furnace. It is then deposited on the
truck released by the locking bar, the end of the charg-
ing rod is lifted out of the socket and dropped into the
socket of the next box, which is then in its turn emptied
into the furnace, and so on. All parts of the mechanism
are operated by electricity.

By means of this machine about 50 tons of material can

be charged in an hour, so that the saving of time in charging and the saving of labour also is very considerable. One machine can work six furnaces, but the makers advise that two should be provided for each six furnaces, so as to avoid delay in case of breakdowns.

The Regenerators.—Many suggestions have been made for changing the position and form of the regenerators. In the Batho furnace the regenerators are enclosed in iron casings, and are placed at the same level as the furnace, one at each corner. This has the advantage that the regenerator chambers are more easily accessible, but it has the disadvantage of occupying more room. There can be no doubt that if possible the regenerator chambers should be below the level of the furnace, so that the gases may rise into it by natural draught. In Hilton's furnace the chambers are separate, each in its own casing, but are placed under the furnace.

The regenerators, as stated above, are occasionally placed in other positions, and sometimes under the working platform. This is very objectionable, as it makes the working platform, which is never very cool, unbearably hot.

The Furnace.—The furnaces are now built of very large size. They are usually rectangular, but elliptical or circular furnaces have been suggested.

In the original Siemens furnaces the roof was dipped in the middle, with the object of deflecting the flame downwards. In modern furnaces the roof is longitudinally, nearly or quite level, a downward direction being given to the gases by a sharp fall in the passages leading to the ports. Mr. F. Siemens contends that a roof slightly domed—*i.e.* higher in the middle—would be better still.

The limit of temperature which can be produced in a furnace fed with producer gas, which consists mainly of carbon-monoxide, is that at which carbon-dioxide dissociates. The dissociation point is not fixed, but is lowered by contact of the gas with hot solids, and therefore Mr. Siemens contends the best way to obtain a very high temperature is to give the gas ample space for combustion.

Tilting Furnaces.—The most important modification of the Siemens furnace for steel making is the introduction of the tilting or rolling furnace. Several forms of this furnace

have been suggested, but it will be sufficient to describe the Wellman furnace, which is the most largely used.

The Wellman Furnace.—The body of the furnace is similar to that of the ordinary Siemens furnace, but it
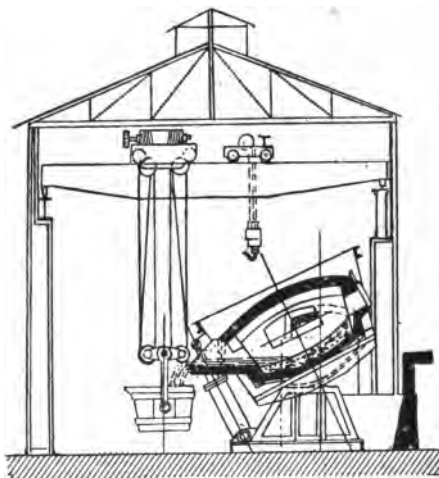

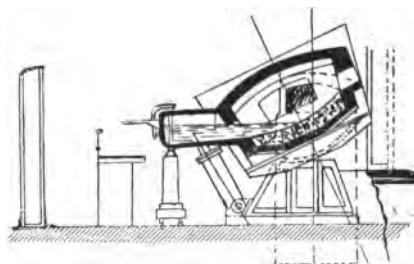Fig. 48.—Wellman Furnace—Pouring into Ladle.

Fig. 49.—Wellman Furnace, with Fore-hearth.

is built independent of the foundations. It is very strongly cased in iron, the ties or stays being firmly riveted, so that it is much like a strong iron box, lined with fire-brick, and with a fire-brick roof (Figs. 48 and 49).

At the bottom of the furnace are three curved iron girders, which rest upon strong supports, and at the back of the furnace is a powerful hydraulic ram, by which the furnaces can be tilted as required. The furnace has working doors on each side, as usual, which are operated by hydraulic cylinders in such a way that they remain closed when the furnace is tilted, and also ports at each end for the admission of air and the carrying away of the pro-ducts of combustion. The ports have to be specially con-structed so as to allow of the tilting (Fig. 50). The end of the furnace is protected by strong steel plates with open-
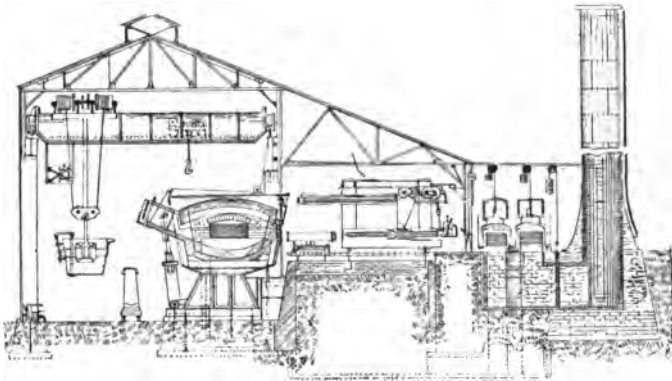
Fig. 50.—Wellman Tilting Furnace.

ings for the ports. The ports themselves are contained in a separate self-contained structure carried on four flanged wheels running on rails.

The uptakes from the regenerators are carried to the level of the bottom of this port carriage, and the rails are laid over them. Round the upper ends of the two passages leading from the regenerators are two cast-iron water-troughs, while round the corresponding openings on the under side of the port are fitted rings projecting down-wards into the water-troughs, thus forming a water seal between the movable port and the fixed uptake, sufficient clearance being given to allow the port to be moved a few inches towards or from the furnace without breaking its

seal. The joint between the ports and the furnace is made by cast-iron rings on the former pressing against corresponding rings on the latter. The joint is quite efficient, the leakage in or out being negligible. When the furnace is about to be tilted, the port chamber is drawn a little back to avoid friction between it and the furnace body. When the ports need repair the whole chamber is lifted away by means of an overhead crane and is replaced by another, the change being made in about half an hour.

The tap-hole of the furnace is so arranged as to be always above the level of the charge when the furnace is upright, so that the hole need only be loosely stoppered with clay. On the outer casing flanges and holes are provided by which a suitable spout or fore-hearth can be bolted on.

The regenerative chambers cannot be under the furnace, but are usually placed two at each end of the furnace.

The furnace is charged in the usual way, either by means of a machine or with liquid metal, and the charge is worked as usual. When the charge is ready, the furnace may be rolled over and the slag poured off, the metal being then poured into the ladle, or it may be rolled so that the tap-hole is below the slag level, the tap-hole opened, and the metal run out from beneath the slag as usual.

A " fore-hearth " may be attached in place of a pouring spout. This closely resembles the Casperson converter ladle described in connection with the Bessemer process (p. 54). It is an iron projection which can be attached to the furnace, lined with fire-clay and provided with a tap-hole and stopper like an ordinary ladle. When it is used the ladle is dispensed with, the metal being tapped directly into the moulds, which are drawn underneath to receive it.

Many advantages are claimed for the rolling furnace :—

    (1.) As the pouring hole is above the level of the bath, it only needs to be loosely stoppered, and the trouble and delay of opening the tap-hole is saved.

    (2.) Since no injury is done to the tap-hole by opening, the life of the furnace bottom is much prolonged.

(3.) If the slag is too abundant, as often happens in the basic process, it can be poured off at intervals during the melting.

(4.) The metal can be completely poured off, no pools being left at the bottom of the furnace.

(5.) Should any hitch occur during pouring, the furnace can be instantly tilted back and the pouring stopped.

The fore-hearth also has several advantages. There is much less cooling than when a ladle is used, so that the metal is tapped hotter. The metal is easily distributed, and should the stopper leak, the furnace can be rolled back till it is repaired. The pouring is also said to be much quicker than from a ladle.

Tilting furnaces of large size are now being built, and some up to 200 tons capacity are in use.

Modifications in Methods of Working.—As remarked above, the open-hearth process is far behind the Bessemer process in output, and the modifications in the open-hearth process have been mainly in the direction of obtaining increased output.

Four modifications only need be mentioned :—

(1.) *Combined Bessemer and Open-hearth Process.*— As the advantage of the Bessemer process is its rapidity of working, whilst the advantage of the Siemens process is the control of the last stages, it has been suggested to blow the charge in a Bessemer converter until almost all the carbon is removed and then to transfer the metal to an open-hearth furnace for finishing. The practical difficulties in the way of always fitting together the two processes have prevented this method coming into use.

(2.) *The Monell Process.*—In this process ore and limestone are charged into the furnace, which must be basic-lined, as the oxide would attack the silica; allowing it to become very hot, and then pouring on the molten metal. The action is very rapid, the slag rises in the puddling process, and is allowed to flow over a cinder notch.

(3.) *The Talbot Process.*—This process, which was introduced by Mr. Talbot in 1900, is now coming rapidly into use. The furnace used is necessarily a rolling or tilting furnace, and it may be of large size (furnaces up to 200 tons capacity being now in use), and is basic-lined. The

furnace is charged as usual at the beginning of the week, and the first charge is worked exactly in the usual way. When the first charge is completed, a portion of the slag is poured off through a slag-notch on the charging side. Then a portion only, usually about one-third, of the charge is poured out into a ladle and recarburised in the usual way. The furnace is then turned up, lime and oxide are added, and then liquid pig iron is run in to make up for the steel poured out, and the charge is worked as usual; another portion is then poured out, and this is repeated through the week, the furnace not being completely emptied till the end of the week.

The reaction is very vigorous, and the elimination of impurities is very rapid. After about 15 minutes most of the ore in the slag is reduced, and a portion of the slag is poured off, the charge being finished by the additions of lime and ore as usual. A cast can be made every three or four hours, but the time will necessarily vary with the nature of the iron used. Mr. Talbot made 30 heats a week at Pencoed in a 75-ton furnace; which would be an output of about 750 tons a week.

Messrs. Jones and Laughlin with a 200-ton furnace, working on hæmatite iron, have turned out as much as 1,420 tons a week. The rapid elimination of the impurities is due to the high temperature at which the reaction takes place, and also to the fact that owing to the pig iron being added to the decarburised metal already in the furnace the bath is always dilute, and the slag is always strongly oxidising.

The method of working will depend somewhat on the character of the iron ; when hæmatite iron is being worked the temperature is kept as high as possible, so that the action may be rapid, the basic-lining ensuring the removal of all the silicon. With a basic charge, on the other hand, especially if high in phosphorus, the temperature is kept as low as is consistent with fluidity, so as to ensure the complete removal of the phosphorus before the carbon is all gone.

Scrap can be used, but the addition of cold scrap delays the process, and Mr. Talbot prefers to melt the scrap in a blast furnace, and thus convert it again into pig iron. The metal is necessarily supplied in the liquid form,

preferably from a mixer, and to ensure rapid working with large furnaces, the ore and lime are charged by means of a Wellman charging machine.

As the furnace is not allowed to cool during the week, and is not exposed to the air, the life of the hearth is prolonged, and only small repairs are necessary at the end of the week.

(4.) *The Bertrand-Thiel Process.*—The peculiarity of this process is that two furnaces are used, the process being commenced in one (the primary), and completed in the second (the secondary). Either fixed or tilting furnaces may be used. In the former case the metal is tapped from the primary furnace into a ladle, which is carried by an
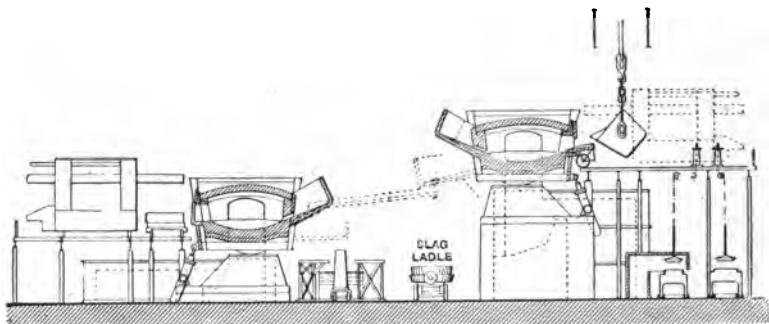
Fig. 51.—Arrangement of Rolling Furnaces for the Bertrand Process.

overhead crane or otherwise to the secondary furnace ; and in the latter case the furnaces are placed back to back, so that by means of a suitable shoot the metal can be poured directly from one to the other. (Fig. 51 shows arrangement of Rolling Furnaces for the Bertrand Process.)

The charge is introduced into the primary furnace in the liquid condition, and is worked, as usual, with a very basic slag, the temperature being kept as low as possible. In about four hours all the silicon, most of the phosphorus, but only little of the carbon, has been removed. In the meantime, limestone, oxide of iron, and any scrap that is to be used are introduced into the secondary furnace, and heated to a very high temperature, and the charge from the primary furnace is poured in. A very

vigorous reaction takes place, the carbon is rapidly elim-
inated, and in a little over two hours the charge is ready
for tapping. It is tapped out as usual, and the furnace
is made ready for its next charge, which, in the meantime,
has been prepared in the primary furnace.

The output, as will be seen, is large, since in the two
furnaces a charge of say 50 tons can be turned out every
4 or 4½ hours. The yield is also higher, 101 tons of steel
having been obtained from 100 tons of pig iron. The
furnaces used must be of large size in proportion to their
contents, as the charge must be shallow and expose a
large surface to the air. Mr. Harbord states that a furnace
which will hold 50 tons for the Bertrand-Thiel process,
would hold 80 to 100 tons if worked in the ordinary way.
The slag from the primary furnace is rich in phosphorus,
but the richness will, of course, depend on the quantity of
phosphorus in the iron. In one case, working a phosphoric
iron, the slag contained nearly 22 per cent. of phosphoric
anhydride. The slag from the secondary furnace contains
but little phosphorus.

The conditions for the removal of silicon and phos-
phorus in the primary furnace are low temperature and
very basic slag, whilst the rapid completion of the pro-
cess in the secondary furnace is no doubt due to the very
high temperature and the absence of phosphorus and
silicon from the slag formed.

The Darby Process of Recarburisation.—This consists
in adding carbon in the form of wood charcoal so as to
be able to add a considerable percentage of carbon with-
out other impurities. The steel is finished in the usual
way, enough ferro-manganese being added to remove the
oxygen; the metal is then, on its way to the ladle, passed
through a small funnel or supplemental ladle to which
the carbonising material is supplied in a steady stream.
The following table will show some of the results ob-
tained:—

Carbon desired.			Before carbonising.			After carbonising.	
0·65	...	...	·069	...	...	{	0·668 first. 0·660 last.
0·70	...	...	·076	...	...	{	0·708 first. 0·700 last.
·80	...	...	·070	...	...	{	0·806 first. 0·804 last.

Future Processes.—In the desire to obtain a large output, there is little doubt that in the future one of these modified methods of work will be largely used, and at present it seems that the Talbot will become very general.

The advantages of the Siemens process, especially the control of the quality of the metal, are leading to its general use, whilst the Bessemer process is gradually falling back, and is likely in the future to be only used for rails and similar articles where the output required is very large, the price low, and absolute uniformity of composition is not essential.

Whether the acid or the basic process will be used will depend on circumstances. Whilst good hæmatite pig can be obtained at a reasonable price the acid process will hold its own, but the basic process has the great advantage that whilst good hæmatite pig can be worked by it quite as well as any other, it can also deal with iron containing phosphorus quite satisfactorily.

The output of steel by the open-hearth process is rapidly increasing; the following figures give the output in tons by the various processes in the United Kingdom for 1904 :—

	Acid.	*Basic.*	*Total.*	*Per cent.*
Bessemer	1,129,224	652,309	1,781,533	35·4
Open hearth ...	2,583,282	662,004	3,245,346	64·6
	3,712,506	1,314,373	5,026,879	100

In the United States the output was—

Bessemer	7,859,140 tons	=	56·6 per cent.
Open hearth	5,829,911 ,,	=	42·7 ,,
Crucible and special	92,581 ,,	=	·7 ,,
	13,859,887 ,,	=	100

In Germany the production was—

	Acid.	*Basic.*	*Total.*
Bessemer ingots ...	423,742	5,525,429	4,949,171
Open-hearth ingots ...	130,546	2,697,760	2,828,306
Direct castings ...	56,409	96,405	152,814
	610,697	8,319,594	8,930,515

The steel production of the world was, in metric tons :—

Austro-Hungary	1,195,000
Belgium	1,069,880
Canada	151,165
France	2,080,354
Germany	8,930,291
Italy	113,800
Russia ... ... ,...	2,811,948
Spain	196,000
Sweden	333,522
United Kingdom	5,107,309
United States	13,746,051
Other countries	415,000
	36,150,320

CHAPTER IX.

WHEN the steel has left the furnace, the plant required for dealing with it is the same by whatever process it was made.

The Ladle.—The steel is poured from the converter or from the furnace into a ladle for distribution to the moulds. The ladle as at present used (Fig. 61), was invented by Bessemer for use with his process. It consists of a shell of steel plates about 1 in. thick, and is lined with some refractory material, usually a layer of bricks. It is circular if its capacity is 25 tons or less, but for larger sizes elliptical ladles are very frequently used. At the bottom of the ladle is a hole in which is fitted a fire-clay nozzle; over this is a vertical steel rod, at the bottom of which is a fire-clay plug which fits down upon the nozzle. The rod is surrounded by a sleeve made up of a series of short fire-clay cylinders luted on with clay so as to protect it from the heat of the molten metal. This rod is rigidly attached to a frame connected with a lever outside the ladle, so that it can be raised or lowered. When it is raised, the nozzle is opened and the metal flows out; when it is lowered, the hole is stopped, and no more metal can flow.

In the Bessemer process, where a circular pit is used, the ladle is carried on a circular ladle crane as already described. In the Siemens process, where the casting pits are usually longitudinal, it is carried on a suitable truck which runs on rails over the casting pit.

The ladle is carried on trunnions so that it can be tilted over to empty out the residual slag. The tilting gear may be a chain attached to the one side, or more usually a worm gear.

Before the ladle is used the lining must be thoroughly dried, or explosion may result when the hot steel is run into it. This is usually done by lighting a wood fire in it,

and keeping it up till the lining is quite dry. In many works the ladle is covered with a hood, through which a pipe from the gas producers passes, and a jet of gas is burned in it. This is more rapid and more satisfactory than the separate fire.

The Casting Pit.—This may be either circular or longitudinal, and must be deep enough to contain the moulds
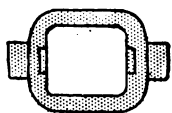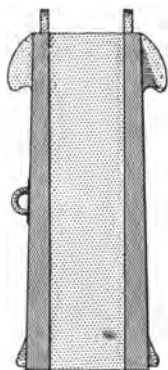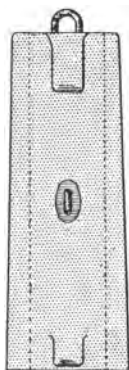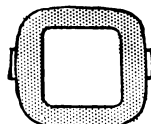

Fig. 52.

Fig. 54.　　Fig. 53.　　　　Fig. 56.

Fig. 55.

Fig. 52.—Top of Ingot Mould. Fig. 53.—Side View of Ingot Mould. Fig. 54.—Section of Ingot Mould. Fig. 55.—Bottom of Ingot Mould. Fig. 56.—Moulds on Carriage.

so that the ladle can be brought over them for filling. A longitudinal pit will be 6 or 7 ft. wide, and the ladle rails will be laid along the top of it. In works where ingots of very varying size are made, several pits of different depths are provided.

The Moulds.—The form of mould (Figs. 52 to 55) now in general use was introduced by Bessemer. It is of

cast iron cast in one piece, and open bottom and top. It is slightly conical, so that it can be lifted off the ingot within, and is provided at the top with eyes or lugs, into which the hook or grab of the ingot crane can pass. The mould is always made slightly longer than the ingot which is to be made. It may be square, rectangular, or any other required shape. The ingot moulds are always cast of Bessemer iron, very frequently direct from the blast furnace, so that when broken or damaged they

Fig. 57.—Ingot Moulds on Carriages.

can be transferred to the melting furnace and converted into steel. The iron used should be of a close fine texture. When the mould is to be used, it is placed with the larger end downwards on a slab of iron, and is luted round with clay.

For special purposes moulds of other forms are used. By means of a central mould with channels from the bottom of other moulds, small ingots may be cast in groups from below. Moulds closed at the bottom are sometimes used, but the open mould already described is in almost universal use for the casting of ingots. When

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a tilting furnace with a fore-hearth is used, the moulds must be movable so that they can be brought under the fore-hearth to receive the metal. The moulds themselves are not changed, but instead of being placed on a slab of metal in the casting pit, they are carried on small trucks which run on suitable rails (see Figs. 56 and 57), the sides of the trucks being carried over the wheels so as to protect them from splashes of metal.

Filling the Moulds.—The ladle is either brought over the mould or the mould under the ladle, as the case may be, the plug is raised, and the molten metal runs into the mould. As soon as it is filled the plug is put down
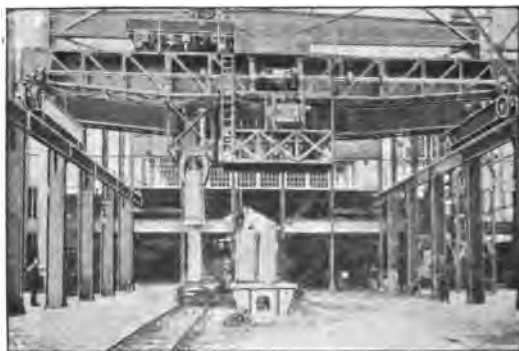
Fig. 58.—Electric Ingot Stripper.

and the ladle or the mould, as the case may be, is moved forward, so that the next mould is in position to be filled. Immediately, the top of the filled mould is filled up with sand, and an iron plate is put over it and wedged tightly in position by wedges passed through eyes cast for the purpose on the top of the mould.

Stripping the Ingots.—As soon as the metal has solidified the mould is lifted away by means of a suitable crane. As a rule, the mould will lift off, leaving the red-hot ingot standing on its base. Should it stick, the mould, with its contained ingot, is lifted a few inches and the mould is struck heavily with a sledge. Should this not do, it is allowed to drop. This will, as a rule, loosen the ingot,

but should it not do so the mould and ingot are lifted over to the ingot pusher, by which the ingot is pushed out. Fig. 58 shows an electric ingot stripper.

Ingot Pusher.—The ingot pusher (Fig. 59) consists of a horizontal or inclined hydraulic ram arranged on a
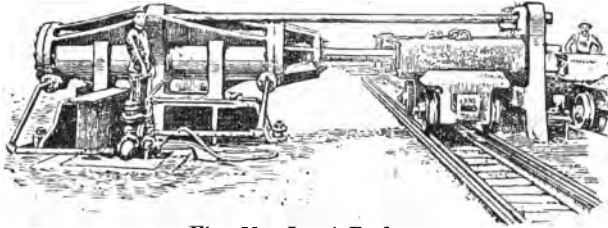

Fig. 59.—Ingot Pusher.

Fig. 60.—View of Ladle and Locomotive Crane showing Casting Pit.

frame, so that the mould and its contained ingot can be placed on it small end up, and the ingot can be forced out by the ram.

When movable moulds are used they are usually at once run to an ingot stripper. This consists of a hydraulic ram and a hydraulic crane. The ram is lowered so as to rest on the top of the ingot and hold it in position whilst the mould is drawn off. The ingot is then moved forward on the carriage and lifted off by another crane, and the empty mould is moved on one side and lowered on to another truck ready to receive it, so that it is ready for use again. The hot ingot is lifted on to a truck and carried to wherever it is required.

Cranes.—Cranes of very many types are used for handling the moulds and ingots. For the Bessemer process with a circular pit there are usually two fixed cranes, so arranged as to command the whole pit. They are always hydraulic, and have a movable carriage on a horizontal arm, so that the mould or ingot can be raised from any part of the circumference of the pit. For the open-hearth process with longitudinal pits locomotive cranes are used (Fig. 60). They run on lines parallel to the casting pit, and are used to draw the ladle along as well as to lift the moulds and ingots. Many types of locomotive crane are in use.

In some works an overhead crane runs along the whole length of the furnaces. In this case a separate locomotive must be used for moving the ladle.

The Slag Ladle.—The slag from the Bessemer converter or Siemens furnace is usually run into a ladle for removal. The slag ladle is often of cast iron, is much smaller than the metal ladle, and is not lined. It is usually set down in a convenient position, so that when the shoot is turned up the slag will run into it. When the slag is solidified it is lifted by the locomotive crane, tilted bottom upwards by means of a chain attached to the bottom, and the slag dropped into a truck for removal. Should the slag stick it is bumped until it falls out.

Sometimes the slag is run on to the floor, and while it is pasty an iron hook with a bent end is stuck into it. When the slag has solidified, the mass is lifted away by the hook, and a few bumps break up the slag and liberate the hook, so that it can be used again.

Heating Furnaces.—If the ingot is allowed to cool it must be heated again before it can be rolled, and this is

done in what are called heating or often reheating fur-
naces. During rolling also it may be necessary to re-
heat the ingot. This will be a convenient place to describe
the forms of heating furnaces and cranes or chargers
used with them.

Heating furnaces may be horizontal or vertical, that
is, the ingot may be charged horizontally through a side
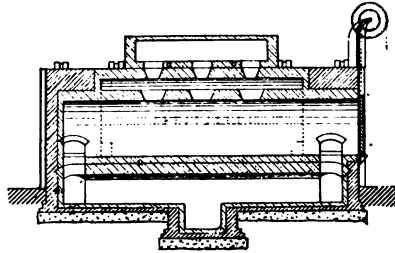door and rest on its side, or it may be charged through
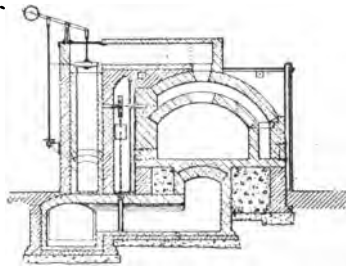

Fig. 61.—Longitudinal Section of Weardale Furnace.

Fig. 62.—Cross Section of Weardale Furnace.

the roof of the furnace and rest on its base. The furnace
will necessarily vary in form according as it is to be used
for heating ingots or plates, but the principle will be the
same in all cases.

The temperature required will not be as high as that
of the melting furnace, since the steel has not to be
melted, but to be heated to a uniform welding tempera-
ture. The heating must not be superficial, but the whole
ingot must be heated to a uniform temperature right

through, and for this purpose a long heating or soaking is necessary. The furnace is therefore often called a soak-ing furnace.

Solid Fuel Furnaces.—These furnaces call for little remark. They are reverberatory furnaces of the usual type. The roof is always low and the hearth is flat. The doors are large enough to admit the ingots or plates which have to be heated. The fuel is usually coal, and sometimes, especially where inferior fuel is
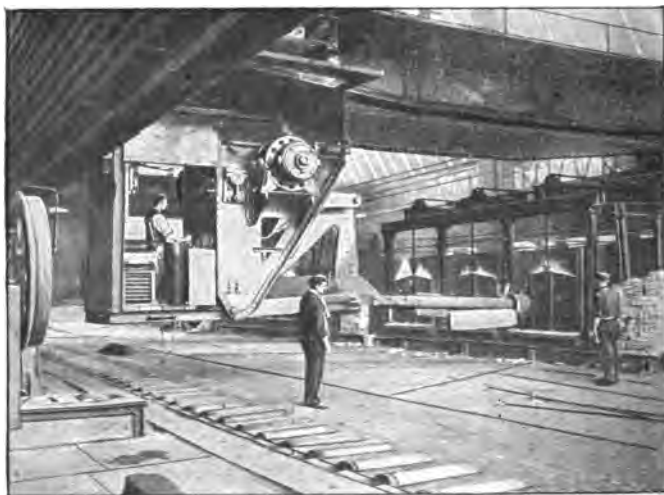
. Fig. 63.—Electric Slab Charger for Reheating Furnaces.

used, the fireplace is made so deep as to be almost a gas producer.

Gas-fired Heating Furnaces. — Siemens regenerative furnaces are very frequently used, as are also furnaces of the new form of Siemens with only one regenerator.

The Weardale Furnace.—This is the only special type of furnace which it is necessary to describe. It was designed by Mr. W. H. Hollis, of the Weardale Steel Company.

The furnace (Figs. 61 and 62) is built with a double roof, so as to leave a space M between the upper and lower roof.

The gas is supplied to a space o above the roof of the furnace and passes by openings K into the space between the two roofs. Here it meets air which has entered by the openings c and has become heated in its passage between the two roofs of the furnace. The flame passes by the openings L into the furnace and spreads out, forming a broad sheet of flame which passes away by the opening D.

The furnace has a row· of working doors at the front and a slag hole at the back, by which any slag which is formed can be drawn off.

The furnace is very economical, the hot products being
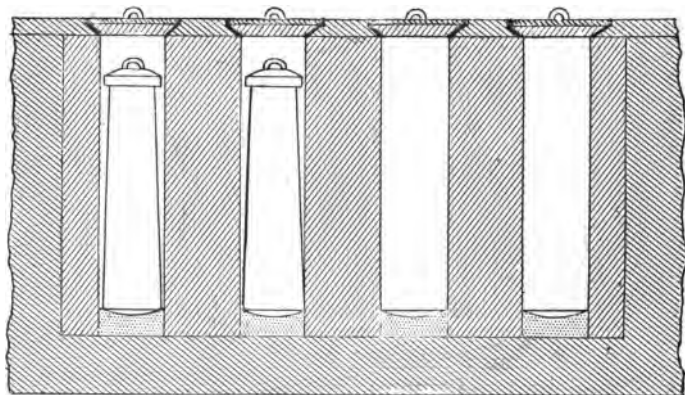
Fig. 64.—Section of Gjers Soaking Pits.

used to raise steam, and giving almost as much ·steam as the fuel would if directly burnt under the boilers. Owing to the arrangement of the ports on the top of the furnace the heating is very uniform, and uniform heating is very important for soaking ingots, and is difficult to attain in a long furnace heated at the ends. The Weardale furnace can be built any length required, and, however long, the heating will be uniform.

Continuous Furnaces.—Ordinary mild steel ingots may be put at once into a hot furnace, but ingots of high carbon steel must be heated gradually. For dealing with these, therefore, continuous furnaces have been designed.

These are heated at one end, so that that end is much hotter than the other, and the ingots are worked continuously forward, either by means of a ram or otherwise.

Furnace Chargers.—For dealing with heavy ingots some charging mechanism is essential. When the furnaces are in line a Wellman charger may be used, in which the charging bar is provided with an appliance for gripping the ingots (Fig. 45). Locomotive cranes of the ordinary type are sometimes used, the ingot being swung from the crane to the door of the furnace and then pushed in by hand labour, or locomotive cranes provided with a grip-charging mechanism have been introduced.

Fig. 65.—Section of Gas-fired Soaking Furnace.
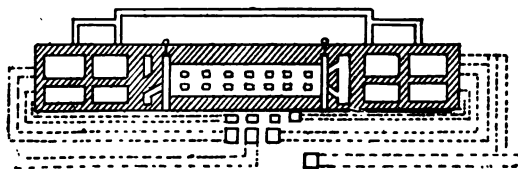
Fig. 66.—Plan of Gas-fired Soaking Furnace.

With furnaces intended for the heating of partially rolled slabs the furnaces are sometimes arranged in a circle, and a rotating crane is used. The circle of furnaces is so placed that the ingot can be taken by the crane from the end of the roughing rolls and put into the furnace, and then, when it is taken from the furnace, delivered to the finishing rolls. An electric slab charger for reheating the furnaces is shown in Fig. 63.

Soaking Pits.—When the ingot is stripped it is still hot, and, though the surface will have partially cooled, the interior will be very hot, perhaps even liquid, and if the heat of the ingot could be redistributed uniformly through it, it would be quite hot enough to be rolled and the reheating could be dispensed with. This was achieved by the soaking pit, which was introduced by Mr. Gjers in 1882, and which very soon became general.

The soaking pit is a brick-lined cavity a little larger than the ingot it is to contain, provided with a well-fitting cover. The pits are always arranged in series. A hot ingot is put into the soaking pit (Fig. 64), and by radiation it heats the brickwork. This ingot is taken out and replaced by another until the pit is hot enough, these ingots, of course, being reheated in the furnace. When the pit is hot an ingot is put in and left till it is thoroughly soaked—*i.e.* till the heat is uniformly distributed—when it is taken out and sent to the rolls and another ingot put in its place.

The soaking pit answers perfectly where there is a regular and continuous supply of ingots of fairly uniform size, but this is not often the case, and if the supply of ingots be intermittent the pit may get too cool to be efficient.

Vertical Soaking Furnace.—The soaking pit in its simple form is now generally abandoned, or, rather, it has been modified into a vertical soaking furnace (Figs. 65 and 66). This is a chamber, placed below the level of the ground, capable of holding 12, 20, or any other number of ingots, and having an opening at the top for each ingot space, provided with suitable covers. At each end is a pair of regenerators by which gas and air can be heated and passed on into the furnace. By this means the temperature can be regulated as required, gas being used to make up for any deficiency in the heat of the ingots. The ingots are lowered vertically into the furnace by a crane, and are lifted out again by the same means.

Position of Soaking Furnaces.—The soaking furnaces should be so placed that the ingots can be lifted directly from the casting pit into them, and from them to the rolls, so that the ingots may have as little time to cool as possible. Suitable mechanism must also be provided for quickly lifting and replacing the covers.

CHAPTER X.

THE cementation process is one of the oldest of the steel-making processes, it having been in use in Sheffield for nearly two centuries. Its origin is unknown, and Dr.

Fig. 67.—View of Cementation Furnace.

Percy states that a good description was given by Reaumar in 1722.

Principle.—When iron is heated in contact with charcoal at a welding temperature, carbon is slowly absorbed, so that the iron becomes converted into steel.

The Process.—The process, as now carried out, differs little from that in use a century or more ago. The pots in which the conversion takes place are made of stone or fire-clay slabs. They are usually about 4 ft. wide, 3 ft. deep, and 12 to 15 ft. in length. Two pots are used in each furnace, and these are placed parallel one on

each side of the fireplace, and are supported on bricks, so as to allow a free circulation of air under and round them, and space is left between the outer wall of the pot and the side of the furnace. The furnace is covered with
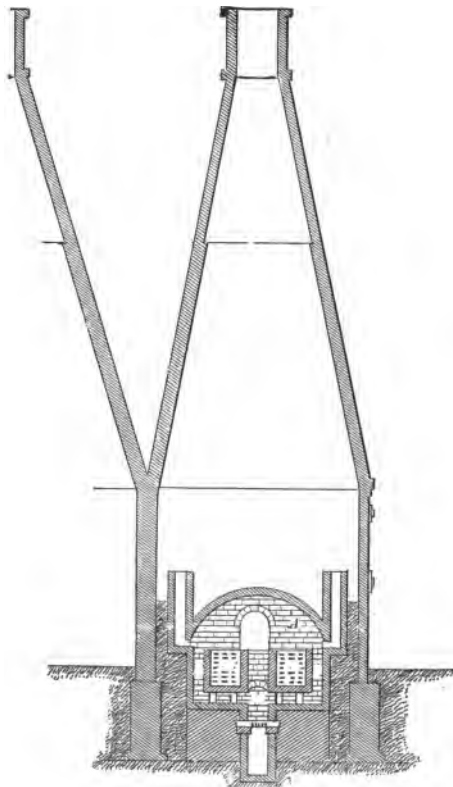
Fig. 68.—Cementation Furnace (Sectional Elevation).

an arched roof, through which are left openings for the escape of the products of combustion, and the whole is usually packed with earth, so as to retain as much heat as possible. The furnace proper is surrounded by an outer wall with a conical chimney or stack to carry off the pro-

ducts of combustion (see Figs. 67 and 68). An opening is left above the fire-door by which men can enter to charge and discharge the pots, which is. bricked up when the furnace is at work, and a square hole is made through the end of each door and a corresponding hole through the outer masonry by which a trial bar can be inserted and withdrawn.

Charcoal is broken up and sifted through a riddle of ½-in. mesh so as to separate dust, and a layer of the small charcoal is spread on the bottom of each pot. On this is laid a layer of malleable iron bars, then another layer of charcoal, then another layer of bars, and so on till the pot is full. The pots must now be covered air-tight, and
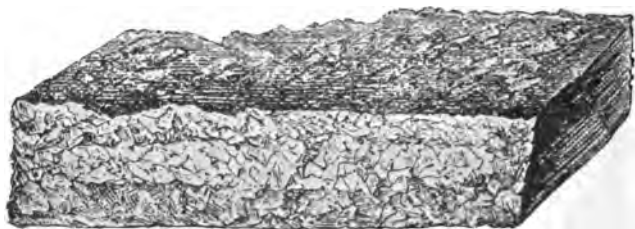
Fig. 69.—Section of Blister Steel—Shear Heat.

for this purpose some material must be used which will not be fusible nor crack at the high temperature to which it will be exposed. The material used in Sheffield is the mixture of fine particles of steel and sand from the grindstones, which is obtained in grinding steel articles, such as blades, etc., and which is known as wheelswarf. This is spread over the top of the pot. As the temperature rises the iron oxidises, and the oxide combines with the silica of the sand, fritting the whole into a solid mass which is quite impervious to air.

As soon as the pots are charged the fire is lighted, and the temperature is brought up to welding temperature in about two days, very gradual heating being necessary, as the pots must be heated through, and it is important not to have the outside much hotter than the inside. The temperature is then steadily maintained for the required time, which may be anything from a few days to a fort-

night or more, according to the amount of carbon it is desired to impart to the bars. The condition of the charge is judged by withdrawing the trial bar, breaking off the end, and examining the fracture. The furnace is then let cool, and, when cool enough, workmen enter and un-
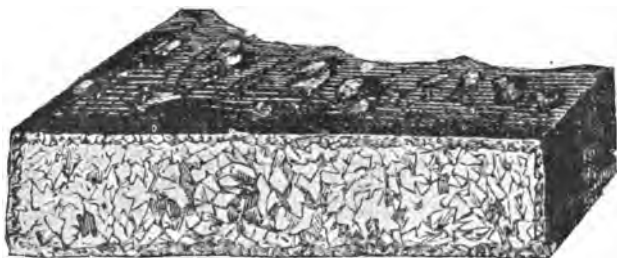

Fig. 70.—Fracture of Blister Steel—Spring Heat.

pack the pots. The whole process occupies somewhere about three weeks, and fifteen or sixteen charges can be worked in each furnace per year, and the life of each pot will be from twenty to forty heats.

The Products.—The bar iron will be found to have

Fig. 71.—Fracture of Blister Steel—Melting Heat.

undergone several changes. (1) It will have increased in weight; (2) the surface of the bar, which was quite smooth when the bars were put in, is now covered with blisters, sometimes a large number of very small blisters, some-

times a larger number of larger ones; (3) the appearance
of the fracture will have become changed, and it will
be found that it varies according to the extent to which
carburisation has been carried (see Figs. 69 to 71).

Classification of Steel.—Seven grades are made, which
are numbered 1 to 6, the last grade usually not being
given a number :—

No. 1.	...	$\frac{1}{2}$ per cent. C.	...	spring heat.
No. 2.	...	$\frac{5}{8}$,, ,,	...	country heat.
No. 3.	...	$\frac{3}{4}$,, ,,	...	single shear heat.
No. 4.	...	1 ,, ,,	...	double shear heat.
No. 5.	...	$1\frac{1}{4}$,, ,,	...	steel through heat.
No. 6.	...	$1\frac{1}{2}$,, ,,	...	melting heat.
No. 7.	...	double cemented		

Intermediate grades are also made, and steel higher
in carbon than No. 7 is occasionally made for special
purposes. No. 1 is now rarely made by cementation,
since it can be made more cheaply by the open-hearth
process.

The carburisation takes place in the bars from
without, inwards, so that the bar when broken will, if
the carburisation has not gone too far, show an inner
core or sap. of unaltered malleable iron, and an outer
layer of more finely crystalline steel. In No. 1 only the
outer skin is converted; in No. 2 the layer of steel is
more distinct, or the sap is more killed. When double
shear heat is reached the thickness of steel is about
equal to that of the sap, and when steel through heat
is reached the sap has disappeared. With further cementa-
tion the size of the crystals of the steel gradually increases,
until in some cases the facets stretch right across the sur-
face. There should be no sharp line of demarcation between
the sap and the steel, but the two should verge one into
the other so that it is difficult to tell exactly where the
one ends and the other begins. A sharp line of demar-
cation indicates that the action has been too rapid.

If the pots or the covering crack and air finds access,
the charcoal is burnt away, and the bars which are ex-
posed to the air become rough and oxidised on the surface,
and the carbon near the surface is burnt away so the outer
skin is of iron, and is therefore tough. The surface of the
bar being covered with magnetic oxide of iron, its tendency

to rust is diminished, and even a slightly aired bar can thus be detected. If the temperature be too high, the surface of the bars may melt, and they are then said to be glazed, and instances have been " handed down by tradition in Sheffield of unskilful converters who had heated the furnace under their charge to such a degree that the whole mass of iron and charcoal had been fused together, and the end of the furnace had to be taken out to remove the contents."

Theory of the Process.—Several views have been held as to how the carbon is transferred into the steel. Among them are the following :—

(1.) *The Gaseous Diffusion Theory.*—The iron is not embedded in solid carbon, but in carbon with large air spaces. This, indeed, would be the case if so-called solid charcoal could be used, because charcoal is very porous, and a large proportion of its bulk is, therefore, air spaces. As the temperature rises the oxygen of the air combines with the carbon and carbon-monoxide is formed, so that the iron is surrounded by an atmosphere of nitrogen and carbon-monoxide. This then diffuses into the iron, but as the carbon-monoxide comes in contact with the iron, carbon is deposited and carbon-dioxide is formed, which then diffuses and so finds it way out. Thus there will be a double stream of diffusion—carbon-monoxide inwards, carbon dioxide outwards. Carbon-dioxide is an oxidising agent, and may oxidise out carbon already deposited, and so for any given point a position of equilibrium will be reached, and then the carburisation will go on inwards till the whole bar is converted.

(2.) *Solution.*—The carbon may diffuse into the iron just in the same way as sugar or salt solution will diffuse into water.

(3.) Professor Arnold holds that the carbon combines with the iron at the surface and forms definite carbides which diffuse into the metal, first a carbide having the formula $Fe_{24}C$, which contains about ·9 per cent. of carbon, and afterwards the carbide $Fe_3C.$; and that the former carbide is formed and diffuses at about 750°C., while the latter is not formed till about 950°C., so that if a bar were cemented at about 800°C., it should be im-

possible to make it take up more than ·9 per cent. of carbon.

It has been conclusively proved that the presence of air is not essential, but that if a steel containing carbon be heated in contact with iron or nearly carbon-free steel, the carbon will diffuse and thus tend to equalise its distribution.

The Blisters.—The blisters are hollow and frequently contain minute fragments of silica and other foreign matter. They occur only at the surface, there being no corresponding cavities in the body of the bar, and are undoubtedly due to the evolution of gas. The bar iron is never perfectly homogeneous, but contains scattered through it fragments of oxide of iron and ferruginous slag ("Iron," p. 17), and it is the reduction of the oxide in these particles that gives rise to the blisters. The reduction cannot be brought about by diffused carbon-monoxide, since the carbon-dioxide formed in that case occupies the same volume as the carbon-monoxide, and therefore there could be no increase in volume such as would be sufficient to produce the blister. If, however, the reduction is brought about by solid carbon, either deposited by the decomposition of carbon-monoxide, by direct diffusion, or in the condition of carbide, gas would be evolved which would occupy an enormously greater volume than that of the solid reducing agent. If the reduction takes place in the centre of the mass the pressure will not be sufficient to form a cavity, but the gas will remain compressed until it can diffuse away. If, however, it be liberated near the surface, the strength of the thin skin of metal above will not be sufficient to retain it, and a blister will be formed.

A large number of small blisters evenly distributed is held to indicate a good steel, whilst fewer large blisters indicate an inferior quality. If the iron from which the steel is made has been well worked, the particles of slag and oxide will be broken up and well distributed, but if the working has been insufficient, the particles will be large and more scattered, and the blisters will correspond to the distribution of the slag and oxide. When mild steel which contains no slag is used there are no blisters.

The Materials.

The Charcoal.—Charcoal from hard wood is preferred but is not essential; birch is used for its production in Sweden, beech in Rhenish Prussia, and oak in England. The charcoal is sifted before it is used, and the old charcoal is re-used.

The Iron.—The best bar iron obtainable is used, and for cementation it is usually rolled into bars about 3 in. wide and ½ in. thick; the larger the bar the longer does

Fig. 72.—Hammering Shear Steel.

cementation take. The highest quality of cement bar is made from the best Swedish iron made by the Walloon process (see " Iron," p. 191), and hammered bars are preferred to those obtained by rolling.

Attempts have been made to prepare steel from bars rolled from ingot metal, made by the Siemens process, but though such metal is much more pure than the ordinary bar iron used, the steel obtained is said to be of inferior quality.

Shear Steel.—The cement bar is not sufficiently homogeneous for use. It must be made so either by a process

I

of hammering or rolling similar in principle to that used with malleable iron, or it must be melted and cast.

For the former process the bars are cut up into suitable lengths; six pieces are piled together into a "faggot" bound with wire at one end, or the one end is surrounded by an iron hoop into which the bars are wedged (see Fig. 70). The free end is covered with powdered clay and borax, is heated to welding heat in a fire, and hammered into a bar under a steam-hammer (see Fig. 72). When the forged end is cold the wire or ring is removed from the free end, and it is heated and welded so that the six bars are hammered down into one. The
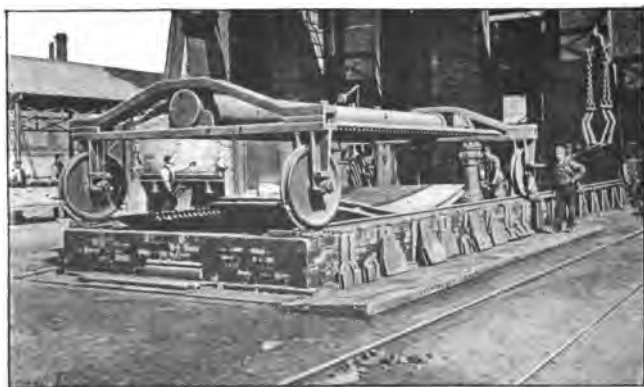
Fig. 73.—Harveyising Sprinkler

steel is then called single shear steel. If greater homogeneity is required the process is repeated, the single shear bars are cut up and welded, and then form double shear steel.

The clay and borax to a large extent protect the metal from oxidation, but some carbon is usually burnt out at the surface.

Case-hardening.—Closely related to cementation is the process of case-hardening, by which a hard surface is given to articles of malleable iron or mild steel. The articles to be case-hardened are packed with charcoal in an iron box, and heated to welding temperature in a

suitable furnace. The time required will vary according to the size of the article and the depth of steel required from two or three hours up to a day. As the surface is usually required to be hard, the articles on removal from the box are quenched in water or oil, the charcoal being at the same time floated away. If no oxidation is permitted the article will remain bright, but if it is exposed to the air, it will become tinted. Very small articles are case-hardened by heating with a layer of ferro-cyanide of potassium, or other substance containing nitrogen and carbon. The only essential for the case-hardening seems to be carbon, but many workers prefer to use charred leather or other organic materials containing nitrogen.

For making " mild centered steel " for pump rods and other purposes, rods of very mild steel are heated for some hours in chests or boxes surrounded by charcoal.

Harveyising.—The process of Harveyising used for hardening armour plates is the same in principle as cementation or case-hardening. The surface of the plate is planed smooth. It is then lifted on to a car which can be drawn in or out of the furnace by means of hydraulic gearing. The top of the car is covered with several layers of fire-brick in which flues are built, on this the plate is placed planed side upwards; on this is spread a layer of powdered charcoal, and then a second plate, planed side downwards, is put on so that the two plates are separated by the layer of charcoal. (Fig. 73, Harveyising Sprinkler.) Walls of brick are built up all round, and the plates are covered with a layer of sand. The car is then run into the furnace, the doors are closed and luted airtight. The heat of the furnace is gradually brought up to welding temperature, and is maintained at that for about a fortnight. The carburisation seems to be facilitated by the weight of the upper plate pressing the charcoal into contact with the surfaces to be hardened. The plates are allowed to cool in the furnace, and are then withdrawn.

Any work that may be required, such as drilling holes, bending, etc., is done before the plate is hardened.

For hardening, the plates are heated to redness in a gas-fired furnace, then drawn out and cooled by means of jets of water made to play on both sides of the plate

so as to cool it as quickly as possible, or in some cases the plates may be hardened by dipping in water or oil.

Minor Processes.

Wootz is the name applied to a hard Indian crucible steel, prepared by melting about 1 lb. of malleable iron with charcoal in small fire-clay crucibles, which are heated in a kind of blast-furnace. About 10 per cent. of fine-chopped wood from the leaves and stems of the *Cassia auriculata* is added to the metal in the crucibles, while the surface of the charge is then covered over with green leaves of the *Asclepis gigantea*, and the crucible is covered either with wetted clay or with a lid luted on to the pot. From twenty to twenty-four of the crucibles are charged, and are then packed into a small hearth supplied with blast by two pairs of bellows, to which the fuel (charcoal) is introduced as required. After heating for from two to three or four hours, the whole is allowed to cool down, the crucibles are removed, and the button or small cake of metal collected in the bottom of each is removed by breaking the crucible. The cakes so obtained are afterwards heated for several hours before the blast in a charcoal fire, whereby they are raised almost to a welding heat, and are finally drawn down into bars of steel, which are usually very hard in temper, and require considerable care in working.

Steel made by this process is of very uncertain composition.

Puddled steel is the product of a decarburisation method conducted in a puddling furnace, identical in many respects with that employed for the puddling of malleable iron, and the procedure observed in the production of puddled steel is also similar to that followed where malleable iron is being prepared. The production of puddled steel was somewhat extensively carried on upon the Continent, but has now been completely abandoned.

The furnace employed for the preparation of puddled steel differs from the puddling furnace already described ("Iron," p. 192) in having a smaller bed, although the grate, flue, and chimney areas are the same; or, in other words, the proportion between the area of the grate-bars,

etc., to that of the bed is made greater when steel is to be produced ; also the depth of fuel upon the bars is increased by the addition of a few inches to the height of the fire-bridge, whereby a greater control over the nature of the flame is possible, and a non-oxidising, neutral, or reducing flame is more readily obtained.

The furnace charge usually consists of from 3 to 4 cwts. of pig iron rich in carbon and manganese. The charge is broken up into fragments of a tolerably uniform size, and is spread evenly over the bed of the furnace, where the whole is then melted down as rapidly as possible to prevent unnecessary oxidation. During the melting-down stage, lasting from forty to fifty minutes, the temperature of the furnace is kept higher than in the ordinary puddling operation, so that on the completion of this stage the whole should be perfectly fused, and well covered with a fluid slag. The oxidation of the carbon and the uniformity of the product are largely influenced by the condition of the slag, and hence the necessity in this process of using a manganiferous pig iron, since the manganese, whilst contributing to the fluidity of the cinder, also diminishes its decarburising influence. At the conclusion of the melting-down period the damper is closed, and the temperature reduced so as to prevent the fining from going on with too great rapidity ; but, as the charge thickens and rises, the damper is carefully raised to keep the charge fluid, while repeated and vigorous stirring or rabbling of the charge beneath the fluid cinder is effected, and after from thirty to forty or fifty minutes floating granules of metal begin to appear, and the boiling stage ensues, whereupon the chimney damper is again closed, and the hearth is filled thereby with a non-oxidising atmosphere and flame which prevent the decarburisation of the charge from proceeding with too much rapidity. The temperature of the furnace gradually falls during the boiling stage, and during this period also, and more especially towards the close of the process, a poor, very fluid, and but slightly oxidising slag is required, since, if the slag be too viscous and highly oxidising, then the decarburisation of the charge proceeds with too great rapidity, and the quality of the product is deteriorated.

Throughout the boiling and fining stage the same
state of effervescence or ebullition due to the escape
of carbon-monoxide from the bath of metal, is observed.
The appearance of the particles, or granules of metal
brought to the surface of the cinder or slag during the
rabbling of the boiling stage, indicates the progress of the
process, as well as the nature and quality of the final
product ; for when the furnace is working satisfactorily,
the granules appear brilliant in lustre, white and gran-
ular, yielding probably a fine-grained steel of good
quality ; but if the particles are coarsely granular and
flaky, then the steel is usually coarsely granular, imper-
fectly refined, and of inferior quality.

The boiling and fining stage usually occupies from
twenty to twenty-five minutes, after which the "balling"
of the charge commences ; this is an operation demanding
care and practical skill on the part of the workman, and
according to requirements the charge is either all balled
at once into a single ball, or it is divided into smaller
portions or balls.

The balling of the charge is effected with the damper
down, and the furnace is thus filled with a non-oxidising,
smoky flame, so that all decarburisation is stopped during
this stage of the process, and the temperature is also kept
lower than during the corresponding period in the pud-
dling for malleable iron.

The shingling of the puddled balls is effected as quickly
as possible, and at a lower temperature than that em-
ployed in the shingling of the puddled balls of malleable
iron ; but more care is required in the earlier stages
of the shingling or hammering of the metal, especially if
the temper of the steel be hard, since the puddled balls
are not so solid, and hence require lighter blows at the
commencement than are permissible when the product is
malleable iron.

The chemical reactions involved in the puddling of
steel are essentially the same, or are strictly analogous
to those already detailed as occurring in the puddling
furnace for the production of malleable iron. Puddled
steel shows a considerable decrease in the proportion of
the carbon, sulphur, phosphorus, silicon, and manganese
present in the pig iron from which it is produced, as is

indicated by the accompanying analyses, published by Schelling, of the original pig iron, the steel puddled there-from, and of the slags produced during the process, as carried on in a gas-furnace at Zorge, in the Hartz, work-ing upon a mixture of white with grey pig iron.

ANALYSES OF PIG-IRON, PUDDLED STEEL, AND SLAGS FROM THE
PUDDLING FURNACE.

	Original pig-iron.	Puddled steel.		Slags at end of the process
				per cent.
Graphite	0·08	—	Silica	20·52
Dissolved or com-bined carbon	2·60	0·94	Phosphoric anhy-dride	5·25
Sulphur	3·09	trace	Ferric oxide	6·24
Phosphorus	0·48	0·075	Ferrous oxide ...	62·14
Silicon	0·99	0·11	Alumina	3·00
Manganese ...	2·01	0·27	Lime and magnesia	1·50

The process is conducted much in the same way as the puddling process for iron, except that for the production of puddled steel the decarburisation or fining of the pig iron is effected more slowly and less completely than in pig-boiling; thus the process for the production of puddled steel lasts from one hour and fifty-five minutes to two hours and fifteen minutes, permitting of only five or six charges being worked off during the twelve hours. The consumption of fuel reaches to 25, 30, or 35 cwt. of coal for the production of a ton of puddled steel. The loss of weight between the puddled steel bar and the original pig iron is between 6 and 9 per cent., or, as might be ex-pected, slightly less than when malleable iron is produced.

The slag or cinder from the puddling of steel is more fluid, is less rich in iron, and is consequently less decar-burising than the cinder occurring in the corresponding stages of the puddling of malleable iron. For maintain-ing this condition of the slags such materials as quartz, clay, mill-cinder, poor slags, etc., are added to the furnace during the melting-down stage; and for still further promoting the fluidity, etc., of the cinder, black oxide of manganese is sometimes added before balling up the metal.

Styrian Process.—In Styria, steel which has a very high reputation is still made by a hearth process.

The ore used is the spathic ore of the Erzgebirge, which consists essentially of ferrous-carbonate, containing about 4 per cent. of manganese, and about 0·057 of phosphoric-anhydride (P_2O_5).

The ore is smelted in small blast furnaces, charcoal being the fuel used, and a white iron, low in silicon and phosphorus, is produced, which is cast into thin plates.

A small hearth about 29 in. long by 20 in. broad, the sides being made of iron blocks, is used. The blast is supplied at one end of the hearth, and is directed downwards at an angle of 25° to 26°.

A layer of charcoal is put in the hearth, levelled and stamped down, a layer of hammer slag is thrown on, and the hearth is filled up with charcoal, which is lighted and the blast put on. As soon as it is hot the bloom of steel from the preceding operation, which weighs 154·2 lb., is put in the fire and heated, and when this is hot enough it is removed and hammered into a bar, and while still red-hot is thrown into a tank of water to harden it.

The plates of pig iron are broken up and made into a pile 1½ to 2 in. in thickness, weighing about 132 lb. The pile is held in tongs, supported by a chain, over the fire at the end of the hearth furthest from the blast. It is thus gently heated, and is moved forward toward the blast, where it is melted. In the meantime, a second pile is introduced at the far end, and is gradually pushed forward. As soon as the iron is all melted the slag is tapped off and a shovelful of wet slag is thrown in to reduce the temperature. This chills the steel so that it can be broken up into blooms, which are hammered out and broken up into smaller bars.

The charge of pig is about 2 cwt., the operation takes three hours, and the production is about 7 cwt. in a day of twelve hours.

The chemistry of the process is very simple. Oxidation is brought about by the air, and, as the amount of oxidisable impurities is small, the oxidation is nearly complete by the time the metal is melted. As the amount of carbon left is somewhat uncertain, the bars are broken and carefully assorted by the fracture.

The following analyses of the iron and steel are interesting :—

			Pig-iron.	Steel.
Carbon ...	...	...	3·430	0 899—1·141
Silicon ...	...	...	0·110	0·020
Sulphur	...	...	0·016	0·005
Phosphorus	...	...	0·066	0·019
Manganese	...	...	1·010	.0·043
Copper	...	...	trace	0·004
Iron ...	...	...	95·368	
			100 00	

Direct Processes.—Many attempts have been made to
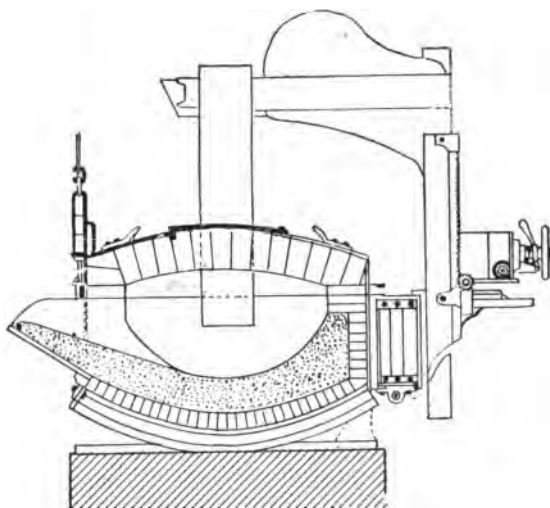
Fig. 74.—Heroult Electric Smelting Furnace.

prepare steel by the reduction of iron ores in presence of carbon, but though they have been used in many parts of the world they have not been very successful, as it is impossible to ensure uniformity of composition. The method, no longer used, though varied in detail, has always been to reduce the ore in hearths at a moderate temperature by means of charcoal, and to retain the re-duced iron for some time in contact with the carbon, or to heat the ore or a pure oxide in crucibles with charcoal.

Electrical Processes.—Several electrical processes of steel making have recently been suggested. The process usually consists of melting pig iron scrap and ore exactly as in the open-hearth process, but using electricity as the source of heat instead of the combustion of producer gas (Figs. 74 and 75). In the Heroult process the furnace used is a small tilting open-hearth furnace, through the roof of which two large water-
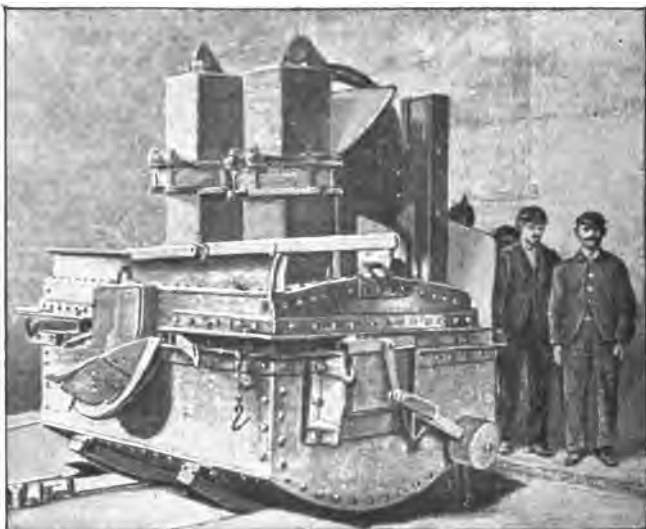
Fig. 75.—View of Heroult Electric Furnace.

jacketed carbons are passed. The current passes from one of these carbons to the bath of metal, and then from the bath of metal to the other, in each case through a short air-gap. The furnace has a capacity of 4 tons, and takes an alternating current of 4,000 ampères at 110 volts. The energy consumed is from 0·1 to 0·153 electrical horse-power per 2,000 lb. of steel. At present the process has only been worked upon a small scale, and is little known beyond the experimental stage. It may, however, come into use in the future.

CHAPTER XI.

Crucible Cast Steel.—Shear steel is always, necessarily from its mode of production, more or less irregular in composition, and many attempts were made to prepare

Fig. 76.—Making Crucibles.

a more homogeneous metal by the fusion of cement bar in crucibles. The difficulties were overcome by Huntsman, who started business in Sheffield as a manufacturer of crucible cast steel in 1770.

Principle.—The melting of the steel, of course, presented no difficulty, but the castings obtained were unsound, being full of blowholes. Huntsman found that by keeping the steel molten in the crucible for some time, or " killing " it, the unsoundness disappeared and good castings could be obtained.

The Crucibles.—The steel is melted in crucibles made of fire-clay, with or without the addition of cinders or other material, and they may be either hand or machine made. In some districts graphite crucibles are used, but they have never become general. The pots ordinarily used are about 13 in. high and 9 in. in diameter, and hold 56 lb. of metal. These are used three times, the charges being 56 lb., 44 lb., and 38 lb.

Various mixtures of refractory clay are used, each works usually having its own formula, and the composition is varied to meet the varying requirements. A little coke dust is added, but if any considerable quantity is used it tends to impart carbon and silicon to the steel. The crucibles must be strong, so as to resist the more or less rough handling to which they are subjected in work (Fig. 76).

The materials for the batch of crucibles—the various clays, the coke dust, etc.—which have been ground to the required fineness, are weighed out and thoroughly mixed on a suitable floor, water is added so as to bring the mass to the required consistency, and the whole is well kneaded by treading with the feet and turning with a spade (Fig. 76), the process being continued till the mixture is perfectly uniform, which will occupy three or four hours, according to circumstances. The clay is then cut up into blocks or " balls," each containing the amount required for one crucible, and this is thoroughly worked by hand until all air bubbles are expelled.

The crucibles are made in a cast-iron mould or flask, the interior of which has the form it is intended to give the outside of the pot. This stands on a bottom plate, in the centre of which is a hole. The mould is well oiled, and a ball of clay is put in it. A plug made of either iron or hard wood, having the form which is to be given to the interior of the pot and with a projecting pin at the bottom, is well oiled and is then forced down into the clay, the pin fitting into the hole in the bottom plate, keeping it well centred, and by means of blows from a mallet it is driven home, and the clay which rises round the core above the mould is trimmed off with a knife. The plug is then withdrawn, the flask or mould is lifted on to the top of a post of small diameter and is slid

downwards, leaving the pot standing on the base on the top of the post. The crucible is finally shaped by hand, the top being narrowed a little, and is then lifted away to a warm place to dry. When hard enough to be handled, the pots are placed on shelves round the melting house, where they are left thirty to forty days to dry thoroughly. Each pot weighs about 25 lb. when dry. It lasts three heats, which is a day's work for a melting furnace, and, as a rule, one pot maker can produce about twenty-four

Fig. 77.—Steel Melting House.

pots a day, and can therefore make the pots for twelve furnaces. Lids, stands, and other articles required are also made, but for these clays of inferior quality are used.

The Furnace.—The melting house (Fig. 77) contains the range of furnaces or melting holes for melting the steel. These are crucible furnaces of the usual type, and in Sheffield are elliptical, 20 in. by 19 in., and 3 ft. deep. They are lined with refractory material, sometimes fire-brick, but more usually with ganister, which is mixed to the required consistency and rammed round a wooden core temporarily placed in position. Each furnace requires relining about once a month. The tops of the furnaces are

level with the working floor, the ash pits, etc., being under-
neath. Each furnace may have its own chimney, or more
usually now all the flues are led into one main chimney.
The draught is regulated by partially closing the draught
hole with a brick. Each furnace is provided with a suit-
able cover. Gas-fired furnaces have been tried; indeed,
the Siemens furnace was very early used for the melting
of crucible steel, charging doors being provided in the
roof of the furnace by which the crucibles could be lowered
on to the hearth. They have, however, not come into
general use.

The Melting.—The pots are heated to redness in an
annealing furnace, and are then placed on clay stands or
bricks, two in each furnace; lids are put on the pots, and
the fire is made up. As soon as the pots are hot, a little
sand is thrown in, if hand-made pots are being used, which
have a hole in the bottom. This frits the stand to the pot,
so that it is lifted out of the fire with the pot.

The bar steel is carefully selected, the quality being
judged from the fracture. It is broken into pieces suffi-
ciently small, the charge is weighed, and introduced
into the pot through an iron funnel or filler called a
charger. The lid is carefully adjusted, and the melting
hole is filled up with coke.

As the coke is consumed the temperature rises rapidly,
and as the fuel burns away more is added, so as to main-
tain the temperature at the highest possible point, and
in three or four hours the charge will be melted or " clear
melted." It is now kept melted for a longer period,
varying from twenty minutes or so to an hour, till it is
" dead melted "; this is the killing. Ferro-manganese
is now very frequently added, about 4 or 5 oz. being used
for each charge.

When the charge is ready the lid of the crucible is
removed, the crucible is gripped by suitable " lifting out "
tongs, the surface slag is rapidly skimmed off, and the
metal is quickly poured, care being taken that the stream
does not touch the side of the mould.

The moulds are usually of iron made in two pieces,
which are held together by rings and wedges. The ingots
are usually cast about 3 in. square, but other sizes are cast
as required.

Chemistry of the Process.—The changes in the composi-
tion of the metal which take place during melting are very
small. The carbon may remain constant, but usually will
be slightly increased or diminished With clay crucibles
there will be a loss, but with graphite crucibles and those
containing a considerable quantity of coke the carbon
will increase. The silicon increases very considerably,
Longmuir states, to from four to six times the amount
originally present, and this increase of silicon is of the
utmost importance. The silicon is derived from the clay
of the crucible, and seems to be mainly taken up during
the " killing " stage. The amount will vary with the com-
position of the clay of which the crucible is made and with
the time of heating. The manganese is partly oxidised,
the loss varying very considerably, but it may be roughly
put down as averaging 50 per cent. The phosphorus is
unchanged, and the sulphur is slightly increased under
ordinary circumstances by about ·02 per cent. The sul-
phur taken up is derived from the coke. The sulphur in
the coke burns to sulphur-dioxide, and this finds its way
into contact with the metal, where it is partially decom-
posed and sulphur is taken up. Therefore coke as free
as possible from sulphur should always be used. Long-
muir gives the following analyses in illustration of the
results of melting :—

	Calculated composition.	Actual analysis.	Loss.	Gain.
Carbon ...	1·117	1·147		
Silicon ...	0·036	0·180		+ 0·144
Manganese ...	0·852	0·430	·422	
Sulphur ...	0·042	0·060		+ 0·018
Phosphorus ...	0·046	0·046		

If the ingot was cast immediately the steel was melted,
a good deal of gas would be given off, and the ingot
would be unsound. After " killing," the casts are made
without the evolution of gas, and the ingot is sound. The
simplest explanation of the change, and the one which
is usually held by practical men, is that during the
" killing " stage the gas is given off, and that therefore
the ingot is cast sound. This, however, does not seem to
be the real explanation, but rather that the silicon taken
up increases the solvent power of the metal for the gas,

and therefore that no gas is given off. The whole question of the formation and prevention of blow-holes is discussed below.

The use of various materials for improving the steel, under the name of physics, is common. Innumerable substances have been suggested, but ferro-manganese is the only one the value of which has been proved.

Subsequent Treatment of the Ingot.—The ingot is " ended," that is, when the ingot is cold the ends are broken off, and from the fracture the melter judges the quality of the metal. The ingot is heated, the surface being covered with a flux, such as powdered fire-clay, borax, or fine sand, which protects it from oxidation (wash welding), and it is then hammered down under a light steam hammer to a billet about $2\frac{1}{2}$ in. by $1\frac{1}{4}$ in., or, if required in bars larger than $\frac{5}{8}$ in., it may be hammered at once down to the required size. The ends are again broken off, the fracture examined, and the billet is reheated and rolled to the required size. The greatest care is required in maintaining a suitable temperature, which varies with the grade of the steel.

Casting Mixtures.—In the preceding paragraphs it has been assumed that the steel had to be melted alone or with the addition of a small quantity of ferro-manganese, and the composition of the resulting steel could easily be calculated. In practice a much wider range of materials is melted, and by arranging mixtures steel of any required composition can be obtained.

If, for instance, a steel lower in carbon than that at hand is required, it can be obtained by melting the steel with the required amount of malleable iron or mild steel.

Crucible steel is sometimes made by melting malleable iron or mild steel scrap, with pig iron, and if only a moderate quantity of carbon is required, so that but little pig iron need be used, a steel of moderate quality may be obtained. Ordinary grey pig is not as a rule available, owing to the high percentage of silicon present. The best variety of pig iron is a white hæmatite iron. Since this will be low in phosphorus and silicon, it may contain sulphur, which will be very objectionable, so a pig low in sulphur must be selected, or white refined iron may be used.

As an example, assume that the following materials are available : (*a*) A mild steel scrap containing carbon ·15, silicon ·01, manganese ·40, sulphur 0·05, phosphorus. 0·05 ; (*b*) ferro-manganese, containing carbon 6·5 per cent., silicon 0·8 per cent., manganese 80·0 per cent., sulphur ·02, phosphorus 0·10 ; (*c*) white hæmatite pig, containing carbon 3·5 per cent, silicon 1·0 per cent., manganese 0·50 per cent., sulphur ·02 per cent., phosphorus ·03 per cent. ; and that it is required to make a steel casting containing 0·75 per cent. of carbon, and that 12 oz. of ferro-manganese is to be added to each 100 lb. of scrap.

	Carbon present.	Required in steel.	Excess.	Deficiency
100 lb. of scrap	0·15 lb.	0·75		− 0·60
·75 lb. of ferro-manganese	0·0488 lb.	0·0056	+ ·0432	
100 lb. white iron ...	3·50 lb.	0·750	+ 2·750	

For each 100·75 of steel and scrap there will be a deficiency of 0·60 − 0·0432 = ·5568 parts of carbon. As each 100 lb. of pig iron has an excess of 2·750 parts, the deficiency can be made up by the addition of $\dfrac{100 \times \cdot5568}{2\cdot75} = 20\cdot25$ lb. So that

	Excess C.	Deficient C.
100 lb. scrap		− 0·60
·75 lb. ferro-manganese	+ 0·0432	
20·25 lb. white iron (·7087 − ·1513) =	+ 0·5568	
121 lb. steel with ·75 % C.	0·6000	0·60

The composition of the resulting steel will be :—

Silicon, in 121 parts—

From scrap		·010
„ ferro-manganese $\dfrac{\cdot8 \times \cdot75}{100}$ ...		·006
„ pig		·203
		·219
		= 0·18 per cent.

Sulphur, in 121 parts—

From scrap		0·05
„ ferro-manganese (·0002 × ·75) ...		— (negligible).
„ pig $\dfrac{\cdot02 \times 20\cdot25}{100}$		0·004
		0·054
		= 0·044 per cent.

J

Manganese, in 121 parts—

From scrap   ...   .   ·40

,,   ferro-manganese $\dfrac{80 \times ·75}{100}$ ...   ·60

,,   pig $\dfrac{·500 \times 20·25}{100}$ ...   .   ·10

$\overline{1·1}$

= ·90 per cent.

Result Tabulated.

Percentage Composition.	(a) Steel Scrap.	(b) Ferro- Manganese.	(c) White Iron.	(d) Resulting Steel.
Carbon	0·15	6·50	3·50	0·75
Silicon	0·01	0·80	1·00	0·18
Manganese	0·40	80·00	0·50	0·90
Sulphur	0·05	0·02	0·02	0·044
Phosphorus	0·05	0·10	0·03	0·047

Steel is also sometimes made by melting together mild steel or malleable iron scrap with carbon, but there is usually a loss of carbon, so that the composition of the steel thus made is somewhat uncertain.

The Steel Foundry.—Steel castings are now very largely used for engineering purposes. For light work the metal is usually melted in crucibles, but for large articles an open-hearth furnace is usually used, and small tilting furnaces are coming into use and have many advantages for the steel foundry. (Fig. 78.) The metal is run into a ladle, which is carried by a crane or otherwise to the casting shop.

The moulds are made much in the same way as for cast-iron, but owing to the much higher temperature of the steel, they must be made of much more refractory material. Special mixtures, of which ganister often forms an important part, are made for the purpose. The moulds are usually dried.

The difficulties in making good castings increase greatly as the steel becomes milder, partly because mild steel dissolves so much gas that it is difficult to get sound castings, and partly because the milder the steel the higher is its temperature of fusion and the more rapidly

it tends to solidify. The shrinkage of steel is also greater than that of cast iron, being about $\frac{1}{4}$ in. to the foot.

The ingates and runners must be of large size, so as not to chill the metal, and ample shrinking heads must be allowed.

Defects in Castings.—Steel cast into ingots, whether of hard or mild temper, is liable to defects which are sometimes very troublesome.

Blow-holes.—This is the most common of all defects.

Fig. 78.—Steel Foundry.

Blow-holes are small cavities filled with gas which occur in castings. There may be few, or there may be so many that the mass becomes spongy or honeycombed. The hard steels, if well "killed," cast well, but the milder the steel the more difficult it is to obtain sound castings.

Blow-holes are caused by the evolution of gas during solidification, and this gas, becoming entangled, causes the cavities. These cavities vary in size from the most minute microscopic cavities up to quite visible holes.

Gases in Steel.—Molten steel dissolves a considerable quantity of gas, the amount dissolved as a rule increasing

with the temperature, and the total amount of gas may be many times the volume of the steel. The molten metal, whether in the Bessemer converter or the Siemens furnace, is more or less in contact with the air or products of combustion, and some gas is therefore dissolved. If it is air, the oxygen is fixed as oxide of iron, or may be converted into carbon-monoxide by the carbon present, whilst the nitrogen remains. If the gas is the product of combustion, then carbon-monoxide may be absorbed, carbon-dioxide will probably be reduced to carbon-monoxide, and
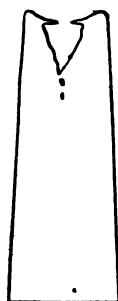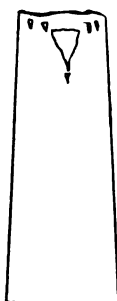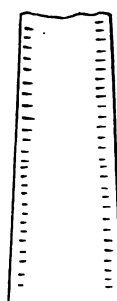
Fig. 79.　　Fig. 80.　　Fig. 81.

Fig. 79.—Section of Ingot, showing Pipe. Fig. 80.—Section of Ingot, showing Internal Pipe. Fig. 81.—Section of Ingot, showing Blow-holes. Fig. 82.—Cross-section of Ingot, showing Blow-holes.

Fig. 82.

any water vapour will be decomposed, the oxygen being used in oxidising iron or carbon, whilst the hydrogen remains in solution, so that the gases present in the steel will be hydrogen, carbon-monoxide, and nitrogen, the proportions, and also the total quantity, varying with the composition of the metal, and also with the conditions by which it has been exposed. The quantity of gas is generally larger in steels made by the Bessemer than in those made by the open-hearth processes.

As the steel cools, the gas, being less soluble as the temperature falls to near the solidifying point, is given off, usually by a steady continuous bubbling; but if the

quantity be large there may be a vigorous boiling, and the metal is said to be wild. As the metal cools rapidly in the mould, the evolution of gas is often very much greater than in the ladle; sometimes, indeed, it is so vigorous that a considerable portion of the metal may be ejected, and it is then said to scatter. The gas which escapes in the ladle or in the mould whilst the metal is liquid cannot, of course, cause blowholes, but the quantity which so escapes is to a certain extent an index to the total quantity present, and, therefore, of that which is likely to remain as the metal solidifies. The gas which escapes whilst the metal is perfectly liquid comes mainly from the ladle; that which escapes during solidification in the mould is usually spoken of as mould gas.

Phenomena of Solidification.—As soon as a mass of steel is poured into a ladle it begins to solidify, the solidification beginning at the outside and gradually proceeding inwards. As the solid metal occupies less area than the liquid, there must be contraction, and what will happen will depend on the conditions of cooling. If the top of the ingot be kept liquid to the last, this will sink downwards so that the top of the solidified ingot will be depressed, forming what is called a pipe. (Figs. 79 to 82, Ingots, showing Pipes.) If the top of the ingot solidifies whilst the interior is still liquid, contraction will still go on, the metal as it solidifies adhering to that which is already solid, and thus a cavity or pipe will still be formed, but will be beneath the surface, and its position will be determined by the position of the last liquid metal. Care is taken to allow an ingot to cool in such a way that the pipe is at or near the surface. If a large ingot be stripped before the interior has solidified, it should never be thrown over, but should be allowed to remain in its vertical position until it has quite solidified. The formation of the pipe is due merely to the contraction of the metal, not to the evolution of gas. If the metal contains gas in solution under such conditions that it will be given off on solidification, the whole state of things will be changed. As the metal solidifies the solid gradually grows inward from the outside, and the gas as given off tends to rise, and if the metal be liquid at the surface, may escape either slowly

or with enough violence to cause scattering. The metal, however, solidifies by the growing inward of crystals, and bubbles of gas are apt to be retained among these, and thus the metal solidifying round them retains them. As any gas liberated tends to adhere to any previously existing bubbles, the bubbles tend to grow inward, increase in size and become elliptical. At a considerable depth below the. surface the cooling surfaces are less definite and the position of the blow-holes becomes more irregular. Very mild steel passes through a long pasty stage before solidification, and this still further tends to retain the bubbles. The escaping bubbles tend to rise through the still liquid metal, and if the top be solidified so that the gas cannot escape, it will be retained in the higher still liquid portion of the ingot. As under ordinary conditions of an ingot cast in a metal mould the top is the last portion to solidify, and the solidification at the top is still further retarded by covering it with sand after casting, the gas rises, and what does not escape becomes entangled in the solidifying top of the ingot, which is subsequently cut off and rejected. When the gas is in solution the bulk of the metal is not increased by its presence, but as soon as it is liberated it necessarily increases the volume, and if it cannot escape it causes the metal to rise, so that whilst a gas-free ingot contracts and forms a pipe at the top, an ingot which has evolved gas rises in the mould to such an extent sometimes that it may reach above the top of the mould.

Blow-holes are always present in steel, and in many cases are not special sources of weakness. If the interior of the bubbles be bright and unoxidised, they may weld up during rolling or forging. If, however, the holes are of large size and do not weld up they are distinct sources of weakness. Sometimes the interior of the blow-hole is oxidised, and the film of oxide prevents welding.

Boring Gases.—The whole of the gas is never evolved before the metal solidifies, some being always retained, whether in minute cavities or in solid solution is uncertain. Gas retained in the solid steel is often called boring gas, because it can be extracted, at least partially, by boring the metal under water with a very fine boring

tool so as to break the metal up into very fine turnings, or it may be obtained by heating the metal in a vacuum, though whether the gas obtained by the two methods is identical in quality and quantity is uncertain. The amount of boring gas is sometimes several times the volume of the steel.

Prevention of Blow-holes.—Many methods for the prevention of blow-holes have been suggested. They may be either physical or chemical.

The Physical Methods.—Among the physical methods may be mentioned, agitating the metal in the ladle, which facilitates the escape of dissolved gas, and casting the metal in moulds, which are rotated rapidly so that the gas is expelled by centrifugal force; but the only physical method which has been at all largely used is casting under pressure, which was introduced by Sir Joseph Whitworth in 1865, a somewhat similar process having been used by Bessemer as far back as 1856.

The principle of this is very simple. The metal is cast in a mould which consists of a very strong steel jacket with a more or less porous lining. The steel is run into this, and great pressure is put on by means of a hydraulic ram, the pressure reaching as much as 20 tons per square inch of horizontal section.

As the pressure is put on there is a vigorous escape of gas and flame, and the ingot is considerably reduced in length.

In the Whitworth and similar processes the pressure is applied at the top of the ingot, where it is likely to be least efficient. In a more recent process patented by Messrs. Robinson and Rodger, of Sheffield, which is an improvement on the patents of Mr. Illingworth, of New York, the pressure is applied laterally.

· The moulds are made in halves divided vertically, the two halves when ready for casting being separated by a packing piece of convenient form and size which can be easily removed. The moulds are arranged in a series in the press in such a way that the spaces between the halves of the moulds when the packing pieces are removed are at right angles to the direction of pressure, as shown in the sketch. The moulds are filled at once by means of a bottom or top runner, and as soon as the surface has

solidified, which takes a few minutes, the packing pieces
are removed, and a steady pressure put on by means
of the hydraulic ram (Fig. 83 shows a plan of an 8,000-ton
hydraulic press for side fluid. compression). The sides
of the moulds are thus forced together; the pressure is
continued till the metal is quite solid, and is gradually
increased till it reaches about 2 tons per square inch. In
the case of large ingots the top is kept open by the use
of a feed rod, a fire-clay ring being laid on the top of the·
ingot, into which the metal rises as soon as the pressure is
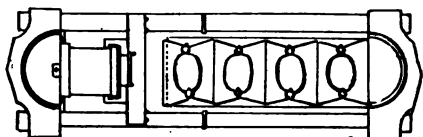
Fig. 83.—Plan of 8,000-ton Hydraulic Press for Side Fluid Compression.

put on. The ingot produced is said to be absolutely sound.
(Fig. 84.—Casting Pit showing Fluid Compression Plant.)

Effect of Pressure.—The effect of the pressure is uncer-
tain; it may be threefold. (1) It may cause the expulsion
of the separated gas; (2) it may prevent the separation of
the gas by causing it to be retained in solution; or (3) it
may simply compress the gas so that the blow-holes become
so small as to be insignificant, or all three actions may co-
operate to produce a sound casting. It is, however,
obvious that the circumstances under which the method
can be used are comparatively few.

Other Methods of Applying Pressure.—Pressure has
been used in various other ways, as, for instance, by the use
of carbonic acid gas, air, and steam, and when castings are
made with a sinking head, *i.e.* a head of metal above the
part of the casting which is required, not only is there the
pressure of the head of metal, but the metal is kept.
liquid longer, so that the gas has a better opportunity
of escaping. The sinking head may be 20 per cent. or
more of the length of the casting, or, in other words,
the casting may be made longer than required for use
by that amount. In ordinary ingot casting the pro-
portion rejected is about 10 per cent. (Fig. 85, Axle
Hammer.)

Fig. 84.—Casting Pit, showing Fluid Compression Plant.

Fig. 85.—Axle Hammer.

Chemical Methods.—If a fragment of aluminium be thrown into a ladle or mould of steel which is " wild," it at once quiets down, and whilst if the metal were poured in its original condition, the ingot would be porous and unsound, after the addition of aluminium it will yield a perfectly sound casting. Castings of very mild steel— known as Mitis iron castings—have been made by the addition of a small quantity of aluminium to almost car- bon-free iron, which, without the addition of aluminium, would have only yielded castings full of blow-holes. Silicon has much the same effect ; the addition of a little ferro-silicon at once quiets a mass of steel, and enables it to yield sound castings, and, as pointed out above, in the " killing " of crucible cast steel, silicon is taken up in the crucible in which the metal is melted.

The action of silicon or aluminium on the gas has been explained in various ways. It has been suggested that it may cause the expulsion of gas from solution. There is, however, no evidence of this, and if it were the case, it would seem that the addition should not quiet the metal, but rather should make it more wild by increasing the amount of gas given off. It has also been suggested that the added metals might destroy the gases by con- verting them into solid compounds ; this, however, is not likely, as neither silicon or aluminium combine readily with hydrogen, nitrogen, or carbon-monoxide. The only other explanation is that the addition of the silicon or aluminium increases the solvent power of the metal for gases not only in the liquid, but in the solid condition, so that the gas is actually retained in solution. The whole question, however, needs further investigation. In prac- tice the addition of aluminium to steel to ensure sound castings is now very general. The quantity required is very small, a few ounces being sufficient for a ladle- of steel, and only the minutest trace of aluminium remains in solution in the metal. Silicon has the same action, and in the form of ferro-silicon is frequently used.

Mild steel can be cast in crucibles by the addition of about 0·1 per cent. of aluminium in the form of ferro- aluminium.

Segregation.—Steel is not a perfectly homogeneous material. In the liquid condition, it must be regarded as

solution of certain compounds in an excess of iron. As the solution solidifies various changes may take place. As a solution of substances which do not remain in solution in the solid condition solidifies, the tendency is for the pure or comparatively pure solvent to solidify, and to leave a more fusible mother liquor which contains a much larger proportion of foreign constituents, so that as solidification goes on, this mother liquor becomes more and more concentrated, and ultimately solidifies. In the case of steel, compounds of carbon, sulphur, and phosphorus tend to pass into this mother liquor, and, therefore, to concentrate in the portions of the mass which solidify last. If the solidification be very rapid there is little time for separation, but if it be very slow, the separation may become so marked that the portions of the ingot which solidify last have a sensibly different composition from the portions which solidify first. This is called segregation, and it is sometimes very troublesome. In ordinary ingot castings the quantity of foreign matter is so small that the segregation is usually of little importance, for the smaller the percentage of foreign constituents, as a rule, the less marked is the segregation.

Campbell gives the following figures as illustrating segregation in a plate 10 in. thick :—

	Carbon per cent.	Phosphorus per cent.	Sulphur per cent.
Centre 6 inches from top ...	·187	·075	·065
Centre 12 inches from top ...	·150	·067	·054
Centre 18 inches from top ...	·179	·067	·054
Centre 24 inches from top ...	·183	·062	·049
Centre 3 inches from bottom ...	·145	·058	·044

If a mass of metal in which segregation has taken place be kept at a high temperature, but below its melting point, for some time, the effects of the segregation may be removed by the diffusion of its separated constituents into the mass of the metal.

Mr. Talbot* has shown that segregation in steel ingots is very much diminished by the addition of aluminium.

Cracks.—It sometimes happens that ingots crack after casting, and cracks may be produced in various ways. The steel in the mould is, of course, much hotter than the

* *Journal of the Iron and Steel Institute,* Vol. II., 1905, p. 206.

mould itself, and the outer skin will, therefore, solidify almost instantaneously. As the mould becomes heated it may draw away from the contracting ingot, and the metal if plastic enough will follow it, but if not, the pressure of the molten metal within may cause a fracture. As cooling goes on, the steel of the ingot cools and contracts more rapidly than the interior, which, being incompressible, will not yield, and thus cracks may be produced. It sometimes happens that as the ingot contracts internal cracks may be developed which produce flaws when the ingot is rolled.

CHAPTER XII.

THE steel, having been cast into ingots, is worked down into the form required—rails, girders, sheets, plates, or whatever else may be required—by forging, rolling, or pressing.

Forging.—Steam hammers were at one time largely used for forging the ingot down to a billet, following the custom of the treatment of the puddled bloom in the manufacture of iron, and as large ingots came to be made, the hammers were greatly increased in size, hammers with moving parts of over 100 tons having been erected in some places. But these have now been entirely abandoned, as the hammer is found not to be efficient for dealing with large masses of metal.

The hammer is now mainly used for light work of various kinds. Tool steel is always reduced to the required form by forging or " tilting," no doubt so called because tilt hammers were used. Light hammers are used, which work very rapidly 150 to 300 blows per minute.

The advantages of the hammer for moderately light work is that the work is much more under the control of tne workman than is the case with rolls, and he can use his skill in modifying the form of the article and in other ways.

The output of a hammer is very much less than that of rolls, and in the latter case the work is therefore much more costly.

Hammers are used for forging steel axles from a circular bar, the anvil and hammer head being suitably shaped, for hammering down ingots for tyres, and for other special purposes.

Before the introduction of mild steel, forgings of large size were made, an ingot weighing 115,000 lb. having been shown in the Exhibition in London in 1873. There were, however, great difficulties in the production of very large

ingots for forging, as a large number of crucibles were required and the pouring had to be absolutely continuous, the pouring from the succeeding pot being necessarily commenced before that from the pot that immediately preceded it was completed.

Rolling.—In almost all cases to-day the steel ingot is reduced to the required form in the rolling mill. The mills differ in details according to the work being done, and it is impossible here to give more than the barest outline of the construction and arrangement of a typical mill.

The action of the rolls depends upon the fact that under a suitable pressure the metal will flow and will take any required form. The ingot to be rolled down, say, into a flat bar or plate, will at each pass through the rolls have to have its thickness reduced from that which it has at starting to the width between the rolls, many passes being required, the rolls being brought nearer each pass when the reduction of thickness is to be considerable. The end of the bar is brought against the rolls, which, by friction, grip it and carry it forward. The plastic metal flows back, there being a wave-like elevation against the rolls, and the bar is therefore elongated almost entirely in the direction in which it passes through the rolls, there being but little lateral extension.

There is, however, always some lateral extension, and the edges of the billet usually become rough and jagged. To avoid these jagged edges and to obtain bars of a uniform section, the rolls are provided with grooves, so that the sides of the bar are pressed against the sides of the grooves and take their form. In this way bars of any required form can be obtained.

In rolling down from a square billet to any required form the greatest care is required in the turning of the grooves on the rolls so as to form such a series that the change from the square billet to the final form will be brought about gradually and in such a way that there will be the least stress on the roll at each pass, that the metal will ultimately take exactly the required form, and that no " fins "—*i.e.* slips of metal which will have to be removed—shall be formed. The engineer in charge has to decide exactly how many passes or draughts will be

necessary to give the reduction of area required, and the
form of grooves in the rolls which will be best for the
purpose.

The Mill.—The mill always has two sets of rolls, the
cogging or blooming rolls by which the ingot is reduced
to a billet of suitable dimensions, square or rectangular, as
the case may be, and the finishing mill in which it re-
ceives its final form. (Fig. 86 shows a cogging mill.)
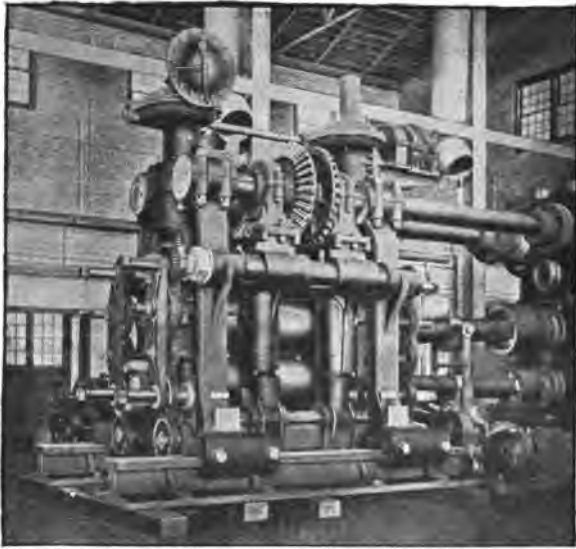
Fig. 86.—Cogging Mill.

The rolls consist essentially of a pair of rolls mounted
one over the other and driven by a suitable power, which
in this country is always a steam engine. The rolls are
both driven in opposite directions, so that they therefore
tend to drag through any substance which is placed be-
tween them.

The rolls for large work are usually made of mild steel,

while for lighter work the plain rolls are of chilled cast iron, and the grooved rolls on which the grooves have to be turned are of a strong, close-grained iron which is not chilled.

The diameter of the rolls varies from 6 in. or so for very small work up to 3 ft. or so for large heavy work, and the length varies up to 10 ft. or so for plate mills, but is usually about 6 ft. The dimensions, however, vary within very wide limits, according to the nature of the work to be done. At each end of the roll is a portion of smaller diameter, the neck which rests in the bearings, and beyond this is a portion which is not circular in section, and is called the wobbler, by which the roll is driven.

The rolls are carried on a strong iron frame. The lower one is fixed in position running in fixed bearings, but the upper one must be capable of adjustment. It therefore runs in bearings which can be raised or lowered by means of a suitable apparatus so as to place the rolls at the required distance apart.

When the rolls are at work it is obvious that the pressure of the lower roll will be on its lower bearings and the pressure of the upper roll on its upper bearings. The rolls are adjusted by means of two screws, one at each end of the rolls, which are operated by hand by means of a lever or a large wheel or, more usually now, by means of steam or hydraulic gearing. It is of the utmost importance that the upper roll should be moved by exactly the same distance at the two ends, so that it should remain parallel to the lower roll. When the roll is operated by hand the wheel is marked so that the position of the two ends can be made to coincide, but when operated by power the two ends are raised or lowered together. As the upper roll will be raised or lowered it cannot be attached to the driving shaft of the engine of a rigid shaft; the shaft, therefore, is loosely attached, the end is made the same form as the wobbler, and the two are united by means of a coupling box. The connecting shaft is always made weaker than the neck of the roll, so that if sudden stress be thrown on the mill the connecting shaft may break sooner than the neck of the roll, the former being much more easily replaced than the latter.

Small mills, such as are used for rolling malleable iron or small steel sections, have the rolls fixed at a definite distance apart, the reduction of area being obtained by passing the bar successively through smaller grooves.

In mills for light work also the rolls are driven continually in the one direction, the bar, having passed through one groove, being returned over the top of the mill, and then passed through the next groove, and so on. Such a mill is called a " pull-over mill."

Sometimes for very light work rolls are used with three rolls (see " Iron," p. 227), the bar being passed in one direction between two, say the middle and the upper rolls, and back between the middle and lower rolls. Such a mill is called a " three-high mill."

In some cases mills are used in which several pairs of rolls are placed, one behind the other, so that the bar passes through them consecutively. Such a roll is called a " continuous " mill, and in a " looping " mill several three-high rolls are arranged in line, the bar being seized as soon as it is partly through one groove and bent round and inserted in the next, so that the rolling is continuous, though not in the same straight line.

With very heavy ingots it would be impossible to return the ingot over the top of the rolls. The mill is therefore reversed at each pass, the bar being passed through in one direction and then back in the other direction. Such mills may either be worked by running the engine continuously forward and using a reversing gear to the mill, or by actually reversing the engines at each pass. The latter method is almost universal.

The Cogging or Blooming Mill.—In this mill the ingot is reduced to a billet of convenient size. It consists of a pair of rolls 30 in. to 36 in. in diameter and 6 ft. to 8 ft. long. These are plain or have broad rectangular grooves for giving the final form to the billet. They are, of course, adjustable. In the early mills the ingot was pushed up to the roll by means of iron rods; then, to facilitate the movements, rollers were provided; and now that very heavy ingots are used, " live rollers " are provided by which the ingot is mechanically carried forward and mechanical appliances are used for turning and rolling the ingots.

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For a distance of 20 to 40 ft. at each side of the rolls is arranged a series of small rollers as long as the width of the mill, the tops of which come a little above the level of the floor, and about 18 in. apart, so that the ingot will rest on several of them at the same time. To the axle of each of these rollers is attached a bevel wheel, gearing with a bevel wheel attached to a shaft driven by an engine, so that they can all be rapidly rotated in the same direction at once, and an ingot placed on them will thus be carried forward to the rolls.

It is also necessary to move the ingot longitudinally— *i.e.* at right angles to the direction of the rolls—so that it may be delivered at the right place and in a position at right angles to the rolls and not obliquely. A series of runners are arranged between the rollers, running on rails beneath, and usually operated by hydraulic power. By moving these the ingot can be pushed into any required position, and as the ingot will also be caught by two of them it will be placed in the required direction. When the ingot has passed a few times through the rolls it will need to be turned on edge. This is done by means of a
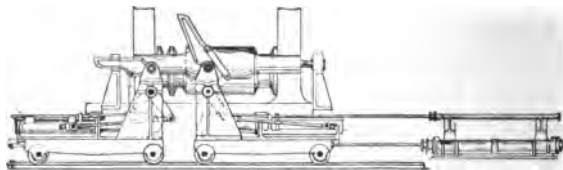
Fig. 87.—Tilting Gear.

tilter. Tilters are of many forms. Essentially they all consist of a carriage running on rails transversely to the rollers (see Fig. 87), with some arrangement of mechanism by which the ingot can be turned over and placed in position.

In the earlier mills, where manual labour was used, a large number of men were required to push forward, guide, and turn (or edge) the ingots, but in modern mills all this labour is dispensed with. The various movements, rolls, live rollers, guides, and tilters, are operated by means of levers from a gallery from which the foreman

can obtain a clear view of the floor, and no labour is required on the floor at all.

Rolling.—The ingot is lifted by a suitable crane and deposited at the end of the floor on the rollers. These are started, and the ingot is carried forward nearly to the rolls. It is then stopped for a moment, and guided into
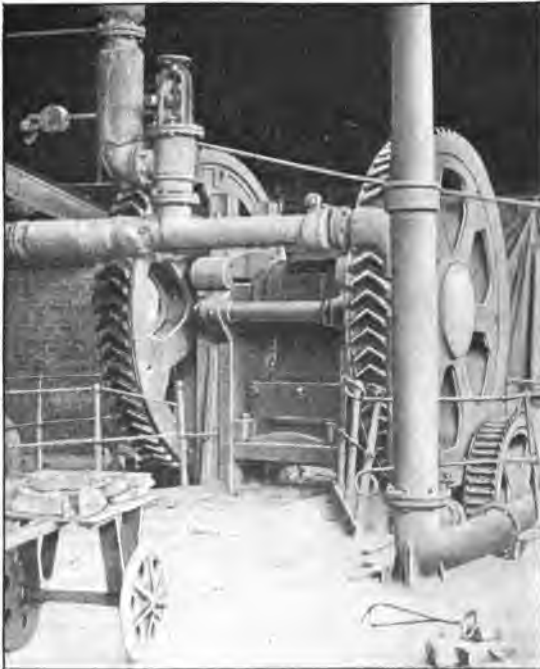
Fig. 88.—Billet Shears.

position. The rollers are again started, the ingot is brought up to the rolls, and passed through. As soon as it is through the rolls and reversed, it is brought up by the live rollers on the other side, again passed through, and so on. When it has passed a sufficient number of times, it is turned on edge by means of the tilter, the top roll is lifted so as to give only the required draught, and the

ingot is passed through again. This is repeated until it has been reduced to the required form, say to a rectangular billet about 8 in. square.

As already remarked, the upper end of the ingot will probably be unsound. This is therefore cut off. For this purpose shears are provided in such a position that the billet can be passed direct from the rolls to it by means of live rollers. The ingot is advanced by the live rollers till as much as is to be cut off at the head is beyond the shear. This is brought down, and the head is cut off and thrown aside. The billet is then advanced till it is beyond the shear, and a piece is cut off the other end. The two pieces which are cut off are put aside as scrap. (Fig. 88.) The billet itself may either be allowed to cool or be sent forward to the finishing mill to be rolled into the required form. In the case of rails, girders, and similar sections, the metal is hot enough to be sent forward to the finishing mill and finished without reheating.

The Finishing Mill.—The finishing mill is very similar to the cogging mill, except that the rolls may be smaller, the size varying according to the sections being rolled. The table in front of the rolls must be very much longer, as the billet is now to be rolled out into a long rail or other section 120 to 200 ft. long, and they may or may not be provided with live rollers. Guides and tilting mechanism are usually not used. The billet is brought forward, passed through the first groove, back through the second, again through the third, and so on, till it has received the required form. The arrangement and form of the grooves will, of courses, vary very much with the section to be rolled, and, as a rule, the rolls need not be adjustable. The resulting section, rail, or whatever it may be, will usually be longer than is required, and also the ends will need to be cut off, as they are sure to be rough. The shears such as are used for cutting billets are not suitable for the purpose, as they would tend to deform the section, and a circular saw is almost always employed. As it is not easy to advance a long bar of metal which is still soft and more or less plastic against the saw, the bar is kept in position against a long fixed guide plate, by which it is kept quite straight, and the saw is swung forward. A saw the blade of which is

carried on a frame suspended so that it can be brought forward in this way is usually called a " flying shear."

The finishing rail or girder is drawn on one side, allowed to cool, and is ready for the market.

Plate and Sheet Rolls.—When plate or sheet is being

Fig. 89.—Slab Rolls for Armour Plate.
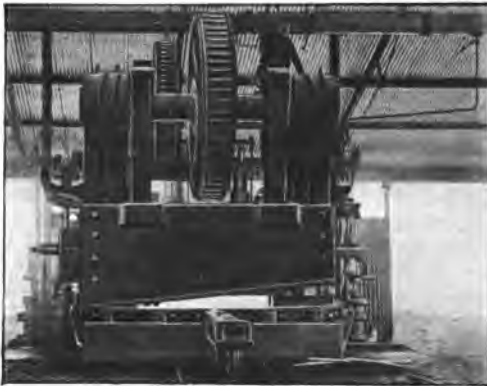
Fig. 90.—Plate Shears.

rolled the first mill is called the slabbing mill, because it is intended to produce flat slabs instead of billets. The rolls are plain or are provided at the end with one or

more " passes," by which a square billet can be produced
if necessary. The rolls are about the same size, and the
general arrangements are much the same as for a cogging
mill for billets. The ingot is passed through the rolls till
it is as long as the slab is intended to be wide, then it
is turned round and passed in the other direction until
the thickness is reduced to the required amount, usually
3 or 4 in. It is then sheared exactly in the same way as in
the case of blooms, except that as it is often necessary to
produce plates of a definite size, slabs of suitable weight
must be provided. Attached to the frame of the shears,
therefore, is a graduated scale by which the size of the slab
cut off can be accurately measured. (Fig. 89, Slab Rolls
for Armour Plate.)

The slab will usually need reheating. In many cases,
no doubt, it would be possible to finish at one heat, but
the surface of the slab will have considerably cooled;
indeed, when it is sheared, the interior is visibly much
hotter than the exterior, and as the rolling of a large mass
of metal at a low temperature would throw great stress
upon the rolls, it is found better to reheat the slab. (Fig.
90, Plate Shears.) The slab is therefore transferred at
once to a reheating or soaking furnace, and, after being
" soaked " for an hour or so, is transferred to the plate
mill.

The Plate Mills.—This consists of two pairs of rolls
coupled and driven together (Fig. 91). They are up to 36
in. in diameter, and the length varies according to the size
plate which is to be rolled. The first pair are of steel or
iron, but the last pair, which have to finish the plate, are of
chilled iron, as a chilled roll gives a better surface than one
of steel. As the roll gets much hotter in the middle, and
therefore expands, it is turned very slightly taper towards
the middle, otherwise the plate would be of unequal thick-
ness and would tend to buckle. To prevent undue heating
the rolls are kept cool by a constant stream or shower of
water, and during rolling the surface of the plate is con-
tinually brushed with a broom of brushwood to remove
the scale. The plate must be transferred from the first to
the second set of rolls, and this is done by the use of a
movable table with live rollers. This is usually sunk into
the ground so that the top is at the floor level and it

can be moved bodily with the plate on it from the first of
one pair of rolls to that of the other, and thus manual
labour is saved.

When the plate has been reduced to the required thick-
ness by passing through both sets of rolls, it is either
received on to a bogie or seized by tongs attached to a
chain and drawn to the cooling floor. This is an exten-
sive floor covered with iron plates, sometimes perforated,
with an air space below, and there the plate is allowed to
cool.

When cool it is straightened either by hammering with
a mallet, rolling on the floor with a heavy roll, or by pass-

Fig. 91.—Plate Rolls.

ing through a plate straightener, a machine which con-
sists of a series of rollers through which the plate is passed.

Shears.—The plate will always be larger than is re-
quired, and sometimes may be cut up into two or three
smaller plates, and the edges will always be rough and
irregular, so that it will be necessary to remove them. The
exact dimensions of the required plate are marked on the
plate by means of a string and chalk, and the plate is
taken to the shears.

The plate is either lifted by hand, a number of men
standing round and lifting by means of a two-pronged
fork, or it may be rested on a bogie or swung by a crane,
and carried to the shears, where it is cut. As the cut
of the shears will usually be much shorter than the width

of the plate, the plate must be held firmly in position and advanced after the stroke in such a way that the cutting is in a straight line. To do this requires considerable skill.

Sheets.—Sheets are thinner than plates. When the thickness is below ¼ in. it is a sheet, above that thickness a plate. Sheets are rolled in small mills much in the same way as plates, except that when reduced to a certain thickness they are passed through the rolls two to four at once, the sheets being separated by passing them through
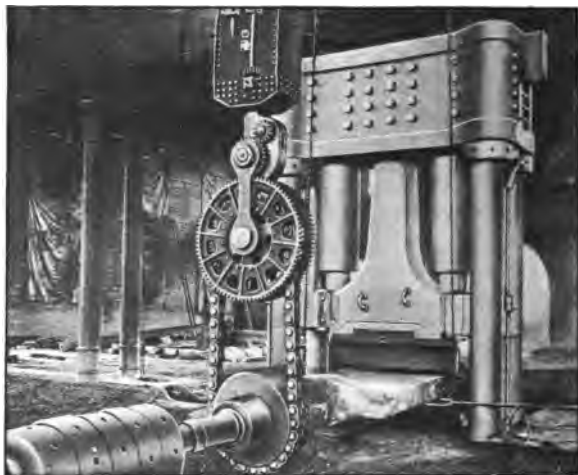
Fig. 92.—Forging Press.

a mill which bends them alternately upwards and downwards, by which the uniting film of oxide is broken up. The sheets are then straightened in a straightening machine.

Forging with the Press.—The hammer is not efficient with large masses of metal, as the impact is largely taken up by the outer layers of the material, and the inside of the mass does not get pressed at all. The roll is more satisfactory, but the limit of pressure that can be attained by rolls is soon reached and is not sufficient for

very heavy work, and for dealing with large masses of metal the hydraulic press is the most satisfactory. The forging press (Fig. 92) is essentially a hydraulic press, capable of giving a very high pressure, a pressure of from 2 to 4 tons per square inch being required, whilst the total pressure may be over 10,000 tons. The cylinders must be made of steel—cast iron is not strong enough—and the pressure may be obtained either direct from the pumps or by means of an accumulator. The ingot is carried by a porter bar, being held in place by a screw collar or other means, and to facilitate turning the ingot is balanced by balance weights on the end of the bar, whilst the bar itself is carried by chains from an overhead crane.

The slab or ingot, having been heated to the required temperature, is put under the press and pressure is put on. The ram is lifted, the ingot is turned if necessary, and again pressed, and so on as required. When a flat plate is being made the anvil and pressing surface of the press are flat, but these may be so shaped as to forge articles of any required form. It is difficult to compare the work of a hammer with that of a press, since the one acts by impact and the other by pressure. Many estimates have been made, but they are probably of little value. The nearest is probably that of Mr. C. Davy, who states that a 3,500-ton press is about comparable with a 100-ton hammer.

The largest press at present in use is that at Homestead, which has a capacity of 14,000 tons, whilst that of Messrs. Beardmore, at Parkhead, is 12,000 tons. It is stated that at Homestead a 50-ton armour plate has been reduced 2 in. in thickness by each squeeze under a 10,000-ton press.

Cold Working.—For some purposes—as, for example, wire drawing and solid tube drawing—the metal is worked cold. Cold working produces hardness and brittleness, and therefore the article must be annealed from time to time. This is done by heating it in a muffle furnace if it is of considerable size, or in a close box packed in some material to exclude all air if it is so small that oxidation might destroy it. When annealed in contact with air, the article is pickled in dilute acid to remove scale before work is resumed.

CHAPTER XIII.

THE use of the microscope for the examination of metals, first suggested by Dr. Sorby about 1864, has gradually extended, and now has come into general use. Very valuable information as to the structure of steel has been obtained, and technical methods of examination have been developed, so that most large steel works now have a microscopic as well as a chemical laboratory.

As steel, however thin, is never transparent, the sample must always be examined as an opaque object, and to allow of the use of high powers reflectors are used in the tube of the microscope. The sample having been cut to a suitable size, is polished until it is perfectly smooth and free from even microscopic scratches. It is then etched with some suitable etching agent, which attacks the various constituents in different degrees, and, therefore, leaves some standing in relief. The sample may either be examined by oblique illumination, in which the light falls on the sample at an angle, or by vertical illumination, in which case the light is reflected vertically downwards in the tube. The appearance of the sample is often very different with the different methods of illumination, portions seeming bright under the one often seeming dark under the other, and *vice versâ;* in the illustrations given V indicates vertical illumination, and N natural or oblique illumination. When high powers are used the illumination is always vertical.

At the outset it may be advisable to explain what the microscope can enable us to detect and what it cannot, as it is very often expected to do that which is impossible. Suppose a material to have solidified from fusion, it may be—

(1.) *An Element.*—In this case it will be perfectly homogeneous, except, of course, for possible physical imperfections such as shrinkage cavities. It will probably

be crystalline, and the crystals may in some cases show their natural form, having crystallised or grown out into the molten liquor, which has subsequently solidified around them. Such crystals are said to be *idiomorphic.* In most cases, however, the distinct form of the crystals cannot be made out. As they have grown from different crystallising centres, they have pressed one upon another, so that in appearance the whole is made up of a series of more or less irregular grains. These are, however, crystals, the external form of which has been destroyed by mutual pressure, and they are said to be *allotrio-morphic.* When such a sample is etched, the crystals being differently arranged or the orientation being differ-ent, that is, the axes not being parallel, the sections of the crystals are in various directions, and are unequally acted on by etching agents, so that the crystal grains often appear of different brightness or different colour and surrounded by a thin line. These are optical effects, and do not indicate any difference in the composition of the grains.

(2.) *A Chemical Compound.*—A chemical compound, being chemically homogeneous, will appear exactly like an element.

(3.) *A Mixture.*—A mechanical mixture can always be distinguished under the microscope unless, indeed, the particles be too small, which is rarely likely to be the case. The constituents of a mixture will necessarily differ in properties, and, therefore, will be differently acted on by etching agents or by colouring agents, so that they may be distinguished and recognised. The arrangements of the constituents in a mixture may vary very much indeed. In almost all cases the constituents will have been in solu-tion, the one in the other, while the mass was liquid, and the separation will have taken place during or after solidification. When the separation takes place during the solidification, the substance of higher melting point solidi-fies first, and the substance of less fusibility is, therefore, forced into the spaces between the growing crystals and there solidifies. It need hardly be remarked that either of the constituents may be an element or a compound.

(4.) *Solid Solution.*—All are familiar with the idea of a solution as formed by dissolving a solid in a liquid,

as, for instance, salt in water, but the idea of solid solu-
tion is not so simple. A solution is not a mere mixture,
because the dissolved solid is evenly distributed through
tne whole bulk of the solution, in particles, probably mole-
cular, so fine that no microscope, however powerful, can
distinguish them, and they cannot be separated by physical
means ; for instance, however dense the solid may be
compared to the liquid, it will show no tendency to sepa-
rate under the influence of gravity. Neither is a solution
a chemical compound, because the constituents are not
present in any definite proportions bearing a simple ratio
to the atomic weights ; these proportions may vary within
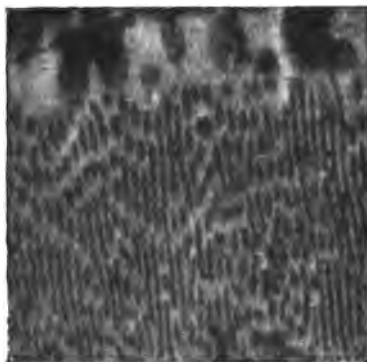
Fig. 93.—Eutectic of Carbides of Iron and Manganese in Spiegeleisen.

wide limits without materially changing the properties of
the solution, and, as a rule, solution is attended not with
the evolution of heat as in the case of chemical combina-
tion, but with the absorption of heat. If a solution of
salt could be solidified into ice without the salt separating,
the result would be a solid solution—that is, a solid
body which still retained the essential properties of a
solution. The elements would not be in chemical com-
bination, nor would they be a mere mixture. The dis-
solved substance would be more or less uniformly
distributed, and no microscope could detect its presence,
and in solidifying the solid solution will behave in all re-
spects like an element or a compound.

Eutectics.—In nearly all cases with which we shall have to deal, the iron when liquid contains some foreign matter in solution. The foreign constituents are slightly soluble in the solid condition, so that what seems like an element or a compound is often in reality a solid solution, but almost always the dissolved body is much more soluble in the liquid than in the solid condition, so that as solidification takes place, a portion, at least, must separate. (Fig. 93, Eutectic of Carbides of Iron and Manganese in Spiegeleisen.) The solidification takes place something in the following manner, the exact details, however, varying with the solubility of the dissolved substance, and the amount of it which is present.

All elements and compounds have a definite solidifying point; that is, the temperature falls until solidification begins, and then remains constant till solidification is complete. The presence of foreign matter in solution, as is well known, lowers the melting point, and produces other changes in solidification. The point at which solidification begins is almost always lower for a solution than for a pure substance, and is lower the larger the amount of the dissolved substance present, the lowering of the freezing point being, for the same dissolved substance, proportional to the amount which is present. Solidification begins at a definite temperature—always lower than the freezing point of the pure substance. As soon as solidification begins, the substance of higher freezing point partly solidifies, and ejects some of the substance held in solution, thus leaving a mother liquor stronger in the dissolved substances, and the solidification proceeds, each portion that solidifies throwing out some of the dissolved substance, and thus still increasing the concentration of the mother liquor and lowering its freezing point. Such a solution, therefore, has no definite freezing point, but gradually solidifies as the temperature falls. At last a temperature is reached when the mother liquor solidifies as a whole, but as it solidifies the solvent and the dissolved body separate, but, of course, remain intermixed. Such a solidified mother liquor in the solid condition is not a chemical compound nor a solid solution but a mixture of the solvent and the dissolved body, is called a " Eutectic." If the solidification has been

slow, it frequently consists of more or less parallel plates
of the two constituents, which can be easily distinguished
under the microscope, but if the solidification has been
very rapid, the two constituents may remain in an emul-
sified condition, the particles being so small that their
detection is very difficult.

Changes after Solidification.—As the particles retain
more or less mobility at a high temperature, changes may
take place after solidification, especially if the cooling is
very slow. These changes may be either of the nature of
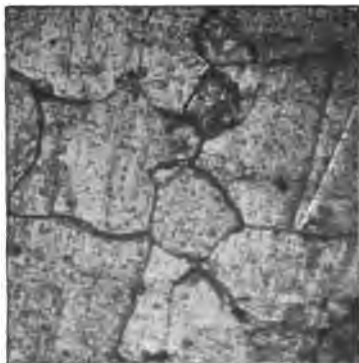
Fig. 94.—Swedish Charcoal Iron   Fig. 95.—Pearlite (Laminated).
(Carbon ·02 per cent.), show-
ing Ferrite.

segregation, *i.e.* the more complete separation of the con-
stituents, or of the nature of diffusion, by which the
differences produced during solidification may be reduced
or destroyed.

Scope of Microscopic Examination.—The power of the
microscope is confined to the detection of distinct con-
stituents which are mechanically mixed, and to the deter-
mination of the general crystalline structure, which is too
fine to be detected by the eye, and beyond that it cannot
go. It gives no power of detecting whether a homogeneous
substance is an element, a compound, or a solid solution.

Microscopic Constituents of Steel.

Pure Iron.—Pure iron is an element, and therefore all that the microscope can show is its structure. It is found to consist of more or less irregular polygonal grains, which are allotriomorphic crystals. Microscopically, pure iron is known as ferrite, but ferrite is not always pure iron, because it may contain a considerable quantity of silicon, manganese, nickel, or other constituents in solid solution without any alteration in its appearance. It is then often spoken of as silicon-ferrite or manganese-ferrite. Ferrite is the basis of malleable iron, mild steel, and grey cast iron. Fig. 94 shows a section of Swedish charcoal iron (carbon ·02 per cent.) showing the ferrite.

Pearlite.—When a steel containing about ·89 per cent. of carbon is allowed to cool slowly, and is then examined under the microscope, it is found to have a peculiar banded structure, a structure which is at once seen to resemble that already described as belonging to a eutectic (Fig. 95). It is not, however, a eutectic because it is not formed when the metal solidifies from fusion, but by after changes which will be described in the next chapter. It is called Pearlite. It was discovered by Dr. Sorby, and was called by him the pearly constituent, because of the play of colours like mother-of-pearl it gives under some illuminations. On examination it has been found that its separate plates are ferrite, and the definite carbide of iron Fe_3C, which is known in metallography as cementite, so that pearlite is alternate layers of cementite and ferrite. As cementite Fe_3C contains 6·7 per cent. of carbon, the pearlite must contain 13·4 per cent. of cementite, and 86·6 per cent. of ferrite, and pearlite has always the same composition.

A steel which contains ·89 per cent. of carbon, and which, therefore, is entirely made up of pearlite, is called a saturated or Eutectoid* steel, and it is a steel of definite composition and properties.

A steel which contains less than ·89 per cent. of carbon is called a hypo-eutectoid. or hypo-saturated steel (Fig. 96). Under the microscope it is seen to consist of a mixture of

* The terms Eutectic and Aeolic have also been suggested, with, of course, the corresponding hypo and hyper.

free ferrite with pearlite, which, of course, also contains ferrite. The amount of pearlite will always be the percentage of carbon multiplied by 112·2, and the percentage of cementite in the pearlite will be the percentage of carbon multiplied by 15.

The arrangement of the pearlite varies very much; it may be only in small quantities scattered through the mass, or it may constitute nearly the whole mass, the ferrite being reduced almost to thin strings.

Cementite.—When the steel contains more than ·89 per cent. of carbon, it is called a hyper-saturated or hyper-
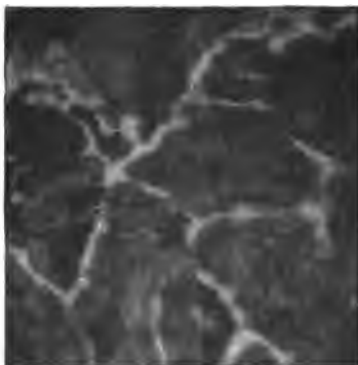
Fig. 96.—Hypo-eutectoid Steel (·55 per cent. Carbon), showing Ferrite and Pearlite.
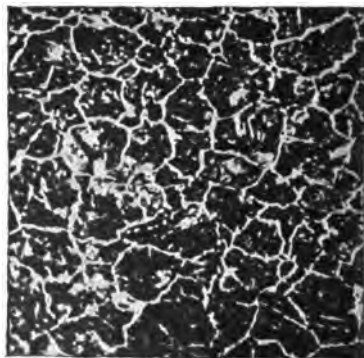
Fig. 97.—Rolled Steel (1·3 per cent. Carbon), showing Cementite Filaments surrounding Pearlite Areas.

eutectoid steel. It now consists of pearlite as before, but in addition there is a hard substance which takes a bright polish, and which is the carbide Fe_3C already mentioned, and which in this connection is called cementite, because of its occurrence in cement bar. (Fig. 97, 1·3 per cent. Carbon Steel [as rolled] showing Cementite filaments surrounding Pearlite Areas.) In such a steel there will be both free cementite and the cementite in the pearlite, but no ferrite, so that it may be said that in slowly cooled steels, cementite and ferrite do not occur together. As the highest amount of carbon which iron can take up is about 4 per cent., the mass can never be pure cementite.

The amount of cementite will be, as before, the percentage of carbon × 15, and the excess cementite will be the amount above that required to form pearlite.

Fig. 106 shows diagrammatically the percentages of ferrite, pearlite, and cementite in steels of various composition.

Carbon.—When very high carbon iron is slowly cooled, and specially in the case of grey pig iron, where the quantity of silicon present is large, the cementite undergoes partial or complete decomposition into ferrite and carbon, and the latter separates either in the form of irregular
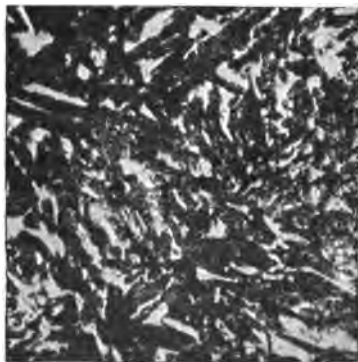
Fig. 98.—Martensite, ·947 per cent. Carbon Steel Water-quenched

black masses of temper carbon, or in distinct crystalline flakes of graphite.

Hardenite and Martensite* (Fig. 98).—In what has been said above it has been assumed that the steel has been cooled very slowly, so as to allow all the constituents time to rearrange themselves. When this is not the case the result is very different. When a steel containing ·9 per cent. of carbon is suddenly cooled, pearlite is not formed, but in place of it is a nearly structureless mass, which, under some conditions, shows a structure made up of fine interlacing needles. This is called Hardenite. It has the same

* Howe uses the term Austenite as synonymous with Martensite, but this is objectionable, as it is likely to lead to confusion.

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composition as Pearlite, and is sometimes regarded as being a definite carbide having the formula $Fe_{24}C$, or as being a solution of the ordinary carbide or of carbon in iron.

When a mass of steel containing up to 2 per cent. of carbon is suddenly quenched the structure depends on the temperature from which it is quenched. At very high temperatures, above 1130° C., even with 2 per cent. of carbon the mass will be nearly structureless, but, quenched at lower temperatures, the amount of carbon that is retained will be less, cementite gradually separating, so that the resulting Martensite gradually becomes poorer and poorer in carbon, till it reaches the Hardenite composition with ·89 per cent. of carbon. Whatever may be the actual composition of Hardenite, Martensite is always regarded as being a solution of carbon or perhaps of the carbide Fe_3C in iron.

When steels lower in carbon than ·89 per cent. are suddenly quenched the carbon remains in the form of Hardenite, which may be mixed with ferrite. As Martensite is allowed to cool over what is called its critical point, 690° C., it breaks up or segregates into pearlite, or, if it be Martensite with more than ·89 per cent. of carbon, into pearlite and free cementite, so that the constitution of steel will vary according to the way in which it has been cooled, and steels may be divided into three groups, according to the carbon content and the rate at which they have been cooled.

(1.) The unhardened or pearlite series, in which the carbon is mainly present as pearlite, with either free ferrite or free cementite, according to the percentage of carbon.

(2.) The hardened or Martensite series, in which the cooling has been very rapid, pearlite and ferrite absent, and the mass is made up of Martensite with or without cementite.

(3.) The normal series, which are intermediate between the two. The structure may be irregular, both structures 1 and 2 being present in parts, but the whole usually approximating more or less closely to 1.

If it be desired to include all varieties of the iron-carbon series another group must be added.

(4.) The graphito-pearlite, or grey cast iron, series, in which the combined carbon is present as pearlite, but there is also a considerable quantity of graphite.

The following table, condensed and slightly altered from Howes' "Alloys," will show the general structure of the iron carbon series :—

PEARLITE SERIES.

Name and Carbon per cent.	Microscopic Composition.					Uses.
	Pearlite.	*Free Ferrite.*	*Free Cementite.*	*Graphite.*	*Slag.*	
1. Wrought iron 0·05 to 0·30	5·5 to 32·3	94·5 to 47·7	—	—	0·2 to 2·0	—
2. Low carbon steel 0·05 to 0·30	5·5 to 32·3	94·5 to 47·7	—	—	—	Boilers, ship and structural steel.
3. Medium carbon steel 0·30 to ·89	32·3 to 100	47·7 to 0	—	—	—	Axles, shafting, tyres, rails, etc.
4. High carbon steel ·89 to 2·00	100 to 89	—	0 to 21	sometimes a trace	—	Little used in the soft condition.
5. White cast iron 2·0 to 4·50	96·0 to 72·5	0 to 4	0 to 27·5	0·0 to 1·0	—	Chilled cast iron.

GRAPHITO-PEARLITE SERIES.

Name and Carbon per cent.	*Pearlite.*	*Free Ferrite.*	*Free Cementite.*	*Graphite.*	*Slag.*	Uses.
6. Grey cast iron 2·0 to 4·50	0·0 to 100	97·5 to 0	—	2·50 to 4·50	—	Castings.

Mottled iron stands between 5 and 6 in composition.

MARTENSITE SERIES.

Name.	Carbon per cent.	Microscopic constitution.	Uses.
7. Low carbon steel	0·05 to 0·30	Martensite with but little carbon	Little used.
8. Medium carbon steel	0·30 to 0·89	Low carbon Martensite to Hardenite	Long springs (tempered).
9. High carbon steel	0·89 to 2	High carbon Martensite.	Tools, etc. (tempered).
10. Chilled cast iron	2·0 to 4·50	High carbon Martensite with disseminate carbon	—

Microscopic Appearance of Iron and Steel.—It is now necessary to describe and illustrate the microscopic appearance of the various steels.

(1.) *Malleable Iron.*—The characteristics of malleable iron are the low percentage of carbon and the presence of intermixed slag and oxide. The mass of the metal consists of irregular grains (allotriomorphic crystals) with here and there small particles of pearlite, these being, of course, more numerous as the percentage of carbon increases. The slag appears in irregular masses of large size when the metal has not been worked, but, when the metal has been worked well, in small dots when the section is at right angles to the direction of rolling, and in long strings when the section is taken parallel to the direction of rolling.

(2.) *Hypo-saturated (Hypo-eutectoid) Steels.*—These steels contain from the merest trace up to ·89 per cent. of carbon. When the steels have been slowly cooled, the carbon is all in the form of pearlite, so that microscopically the steel consists of a ground mass of ferrite, with a certain amount of pearlite in it. The amount of pearlite will, of course, vary very much. The pearlite may be present in islands larger or smaller, according to the amount present, surrounded by a sea of ferrite, or the ferrite may be reduced so as to form continuous skeleton, or it may be reduced as the carbon increases to a skeleton of thin lines breaking up the mass of pearlite.

When a steel of this kind is suddenly cooled, the structure varies both with its composition and the temperature from which it was quenched. The temperatures are best indicated by the critical points Ar_1 (about 86° C.), Ar_2 (about 750° C.), and Ar_3 (about 690° C.), the exact meaning of which will be explained in the next chapter. When a steel containing about 0·1 per cent. carbon is quenched from a temperature above Ar_3, it consists of a mass of low carbon Martensite broken up by a skeleton of ferrite. Quenched at lower temperatures, but above Ar_1, the Martensite decreases in quantity, and therefore increases in carbon content, whilst the ferrite increases.

When the percentage of carbon is much above ·1, quenched above Ar_2, the mass is made up entirely of Martensite, while between Ar_2 and Ar_1 the structure is the same

as that described above, except that the quantity of Martensite is much larger.

(3.) *Saturated or Eutectoid Steel—i.e.* steel with about ·89 per cent. of carbon. Cooled slowly, or quenched below Ar_1, the whole mass is pearlite; quenched above Ar_1, it is Martensite or, in this case, hardenite.

(4.) *Hyper-saturated or Hyper-eutectoid Steel.*— Quenched below Ar_1, or allowed to cool slowly, the section shows a ground mass of pearlite, broken up by a skeleton of cementite, which, in the case of very high carbon steels, may be broken up into islands. Quenched at higher temperatures, the ground mass is Martensite, through which are scattered islands of cementite.

Other Micro-constituents in Steel.—The micro-constituents of steel described above are those which may be called essential. There are others which are produced under certain conditions, and, these being transition forms, their claim to be considered as constituents has been disputed. As the names are, however, regularly used, they must be understood.

Minor Constituents.—Three such constituents have been described, and the more important of them will be referred to again in the next chapter. They are :—

Sorbite, Trosotite, and Austenite.

Sorbite.—It has been pointed out that steels consist of various constituents, according to their composition and rate of cooling. The separation of these constituents takes time, and if the change of temperature be too rapid to allow of complete separation, intermediate products, consisting of more or less unseparated or unsegregated constituents, will result. In the case of a low carbon steel slowly cooled the constituents are ferrite and pearlite, whilst in a high carbon steel they are pearlite and cementite. If the cooling is so slow as to allow the Martensite to break up into the ferrite and cementite, but not sufficiently slowly to allow these to separate as distinct plates, the steel is said to have a sorbitic structure, or sorbite is said to be produced. Sorbite may therefore be regarded as unsegregated pearlite. It is readily coloured by tincture of iodine, but shows no, or at least only incipient, striæ. (Fig. 99, 1·3 per cent. Carbon Steel Oil-tempered.)

Trosotite.—When a steel is quenched just at the recalescence of critical point the passage of Martensite into pearlite is hindered. A trosotite is produced. This, therefore, is also a transition form.

Austenite.—The nature of this constituent is very uncertain. It is produced when steel containing about 1·5 per cent. of carbon is suddenly quenched in iced brine from above 1,000°. It is softer than Martensite, and can be scratched with a needle, while Martensite cannot. It is not coloured by nitrate of ammonium. Professor Hone uses the term Austenite for the stable condition of the solid solution of carbon in iron, or whatever else it may be,
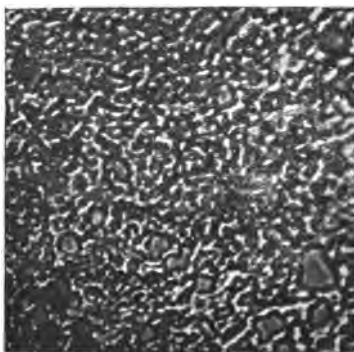
Fig. 99.—Steel, 1·3 per cent. Carbon Oil-tempered.

Fig. 100.—Steel, 1·6 per cent. Carbon Brine-quenched.

which is the basis of hardened steels, considering Martensite as being only an arrested stage of the transformation of Austenite into ferrite and cementite. (Fig. 100, 1·6 per cent. Carbon Steel, Brine-quenched.)

Microstructure of Irons.

Cast Iron.—As closely related to the structure of steel, a brief account may be given here of the microstructure of cast iron.

There are two quite distinct varieties of cast iron, distinct as to character, composition, and uses—grey and white irons.

Grey Cast Iron (Fig. 101) is characterised by the presence of a large quantity of free graphite and only a small quantity of combined carbon. The graphite, under the microscope, appears as minute straight or curved lines. The combined carbon is present as pearlite, much in the same form as in steel containing the same amount of car·· bon. The ferrite, however, is not pure iron, as in steels, but contains a large quantity of silicon and manganese in solution, so that it is a silicon-manganese ferrite. Grey cast iron may therefore be regarded as being closely related
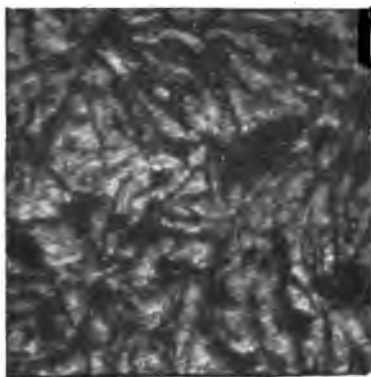
Fig. 101.—Grey Cast Iron.　　　Fig. 102.—Micro Section of
White Iron.
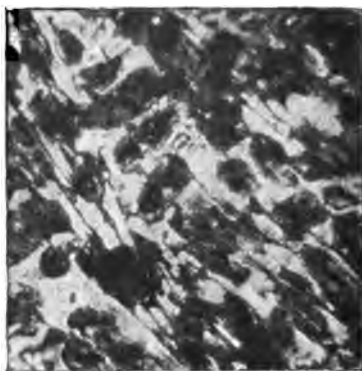
to steel, the differences being the compound nature of the ferrite and the presence of the free graphite.

White Cast Iron contains most of its carbon in the combined condition, and consists, therefore, of a mixture of pearlite and cementite, together with carbide of manganese, the ferrite of the pearlite also containing some silicon and manganese. (Fig. 102, Micro Section of White Iron.)

Accidental Constituents in Steel.—The constituents of steel described above are due entirely to the carbon and iron, and may therefore be regarded as being essential to the steel under the existing conditions of composition and cooling, but other constituents or impurities may be present which may modify the structure.

Silicon, Manganese, and *Nickel* do not form separate and distinct constituents, but dissolve in the ferrite, somewhat altering its character and forming silicon, manganese, or nickel ferrite, as the case may be.

Sulphur.—Sulphur existing as sulphide of iron tends to form a thin, mesh-like structure surrounding the grains of iron.   On the addition of manganese more or less definite grains, probably of sulphide of manganese, are formed.   The presence of a separated, brittle, and fusible material, such as a sulphide of iron, even in small quan-
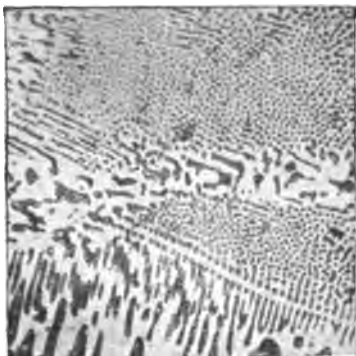
Fig. 103.—Phosphide of Iron
Eutectic (10·2 per cent. P.).
(Stead.)
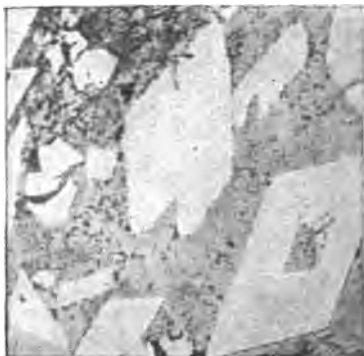
Fig. 104.—Phosphide of Iron
Crystals.   (Stead.)

tity, would account for the red-shortness of steel containing sulphur.

Phosphorus.—Iron can retain phosphorus to the extent of about 1·7 per cent. in solid solution, so that it does not show under the microscope, as far, at least, as definite structure is concerned, except that the presence of phosphorus seems to lead to increased size of grain in the metal, but on etching with very dilute nitric acid the polished surfaces become transiently coloured, the colour disappearing on continued etching, but a brown, or ultimately black, stain being left on the surface of the metal. When the quantity of phosphorus is large a eutectic containing 10·2 per cent. of phosphorus crystallises out,

and when there is more phosphorus than this, definite crystals of Fe_3P separate.

In presence of carbon the quantity of phosphorus that can be held in solution is very much less, and gradually decreases as the amount of carbon increases. The following table, given by Mr. Stead, shows the effect of the addition of carbon to an iron saturated with phosphorus :—

No.			Carbon per cent.	Phosphorus.		
				Free Fe₃P.	*In solution.*	*Total.*
1	...	...	Nil	Nil	1·75	1·75
2	...	...	0·125	0·18	1·37	1·55
3	...	...	0·180	0·59	1·18	1·77
4	...	...	0·70	1·00	0·75	1·75
5	...	...	0·80	1·06	0·20	1·76
6	...	...	1·40	1·16	0·60	1·76
7	...	...	2·00	1·18	0·55	1·73
8	...	...	3·50	1·40	0·31	1·71

The phosphide eutectic may separate as a brittle envelope surrounding the grains of iron.

When the carbon rises above 2 per cent., the eutectic is of a complex character, containing iron, carbon, and phosphorus. In pig irons it often separates in distinct globules. Fig. 103 is a section showing the phosphide of iron eutectic (10·2 per cent. P.), and Fig. 104 is a section showing the phosphide of iron crystals.

CHAPTER XIV.

HEAT TREATMENT OF STEEL. THEORY OF STEEL.

Hardening. —The effect of quenching or sudden cooling on steel has been already mentioned. In the case of high carbon steels, the metal becomes hard, and more or less brittle. The tensile strength is increased, but the durability is diminished. It is usually stated that only high carbon steels are hardened by sudden cooling. This, however, is not correct; all varieties are more or less influenced, but the change is the greater the larger the proportion of carbon present, and, therefore, it is only for high carbon steels that the process is commercially used.

The change from the hard to the soft condition takes place during a comparatively short range of temperature, somewhere below 700° C., which is, therefore, called the critical temperature, and the more rapidly the cooling takes place through that particular range, the harder will the metal be. Rapidity of cooling down to or beyond the critical range has but little influence.

The following figures, given by Professor Howe, show the effect of variations in the speed of cooling:—

Cooled in			Tensile strength. Tons per sq. in.	Elongation per cent. in 2 inches.
Iced brine ...	...	...	106	2·0
Cold water ...	...	...	90·6	1·5
Oil	...	...	78·	2·9
Air	...	...	38·7	27·76
In furnace ...	...	...	35·8	28·15

The cooling in air represents normal cooling, whilst that in the furnace will be extremely slow.

In practice, water and oil are the two hardening agents used. Water has a very high specific heat, and is very mobile, and is, therefore, the most efficient, whilst oil has a lower specific heat, and is less mobile. For very small articles mercury is sometimes used, as it gives a greater hardness than water, owing to its high conducting

power, but as its specific heat is low a large quantity is required. Small articles are hardened by dipping, whilst larger articles are often sprayed with water. For experimental purposes for small articles iced brine which has a temperature of 0° C. is often used. Whatever method is adopted, care must be taken that the cooling is uniform, or the article may warp or crack. It is evident that only a very small article can be hardened anything like uniformly through, as in the case of a large piece of metal, however rapidly the exterior may be chilled, the interior will only cool slowly.

Not only should the cooling be uniform, but the article being hardened should be at a uniform temperature. The smith's forge is often used for heating small articles, while larger ones are heated in a reverberatory or muffle furnace, which is built of a suitable size and form, and is so arranged as to allow of the ready removal of the article. Very small articles are often heated in a furnace packed in an iron box or tube. The temperature required is not very high, up to about a cherry red.

Tempering.—A tool which has been water-hardened is usually too hard and brittle for use, and the hardness and brittleness must be reduced by a process of letting down or tempering. The article is heated 'to a moderate temperature—the less the hardness is to be reduced, the lower will be the temperature—and is then either allowed to cool in air or quenched in water, the method of cooling used making no difference to the resulting hardness, as in any case it is far below the critical temperature.

The accurate adjustment of the annealing temperature is of the utmost importance, and many ways of determining it have been suggested. The usual method depends on the fact that when iron or steel is heated in air a film of oxide is formed which gradually increases in depth of tint as the temperature rises, and by this tint the skilled workman can determine when the right temperature is attained. Great skill and judgment are required, because the tint depends not only on the temperature, but on the time of heating. Other methods of heating that have been suggested are the use of an oil bath, the appearance of the oil giving an indication of

the temperature, or heating in a bath of molten lead the temperature of which can be determined by means of a suitable pyrometer.

The lower the temperature of tempering, the less will the hardness be removed, and it is obvious that for making an article where great hardness is required, not only must the correct temperature be used, but the steel must be of suitable composition.

The following table, slightly abridged, from Professor Howe's " Steel," will give the usual tempering temperatures :—

Oxide tint.	Temperature.		Uses of the steel.	% Carbon in steel.
	C.	F.		
White	—	—	Tungsten steel (HARDEST).	
Pale yellow	220	428	Lancets.	
Straw	230	446	Razors, surgical instruments	1·5
Golden yellow	243	469	Razors, penknives, hammers, taps and reamers, cold chisels for cutting steel.	1·3
Brown	255	491	Cold chisels, shears, scissors, hatchets.	
Brown, dappled with purple	265	509	Axes, planes, lathe tools for copper.	
Purple	277	531	Table-knives, large shears, wood-turning and cutting tools, cold chisels for soft iron.	
Violet	—	—	Cold chisels for brass.	0·9
Bright blue	288	550	Swords, coiled springs.	
Full blue	293	559	Fine saws, augers.	0·8
Dark blue	316	600	Hand and fret saws, chisels for wrought iron and copper.	
Just visibly red in the dark	—	—	Spiral springs, clockmakers' purposes (SOFTEST).	

Annealing.—When the heating is continued to a low red heat, and the metal is then allowed to cool slowly, it attains its softest condition, the martensite has ample time to change into ferrite and cementite, and this to segregate into well defined pearlite, and all stress produced by making is eliminated. Such metal is annealed.

Recalescence.—If a mass of a substance which undergoes no change be allowed to cool, the temperature falls continuously, until the temperature of the surrounding air is reached, in such a way that if a curve be drawn by

taking the temperature as ordinates and the time as abcissæ, and a curve be drawn through the points representing the temperature at each time interval, the curve will be continuous. If the temperature of a piece of cooling, high carbon steel be determined and plotted, the result is different. The cooling curve will be normal till a temperature of about 670° C. is reached; then the cooling is retarded, the curve becoming, for a short time, a horizontal line, or, perhaps, even sloping upwards, after which it resumes its continuous fall. As cooling by radiation must be going on, this retardation of cooling can only be due to an evolution of heat within the mass, by which the loss is balanced. This is what takes place, and in the case of large masses of steel, the evolution of heat may be sufficient to cause the mass to glow more brightly, whence the phenomena has been called recalescence. The point of retardation of cooling is the critical point, at which the martensite passes into pearlite, and it is, therefore, the point over which the cooling must be very rapid, if the carbon is to be retained as martensite, and the steel preserved in the hard condition. The martensite or hard condition is, however, an unstable condition at ordinary temperatures, but the metal is too rigid to allow of change. If, however, the metal is gently heated as in tempering, a certain amount of molecular freedom is given, the martensite can, to a certain extent, pass over into the pearlite condition, and so the hardness is reduced. The higher the temperature of heating, the more readily will this change take place, and, therefore, the softer will be the resulting steel, and at about a red heat the change becomes complete. This critical point is indicated by the letters Ar₁. If a piece of ordinary steel be heated slowly, a critical point is reached when heat is absorbed, and when the pearlite passes over into martensite, this being the reverse change to that which takes place on cooling, and the critical point is indicated by the letters Ac₂. The critical point for heating does not exactly coincide with that for cooling, but is slightly higher. The reason for this is that there is always a certain resistance to change, which tends to produce a retardation.

Cooling of Mild Steel.—When a very mild steel con-

taining only a small percentage of carbon is allowed to
cool and the temperature is taken by means of a very
delicate pyrometer, the phenomena become more com-
plicated. As the temperature falls, there is a retarda-
tion of cooling at about 820° C., then another at 730° C.,
and finally the third at about 690° C., the last being the
Ar_1 point already mentioned, and indicating the change
from the martensite to the pearlite condition. The three
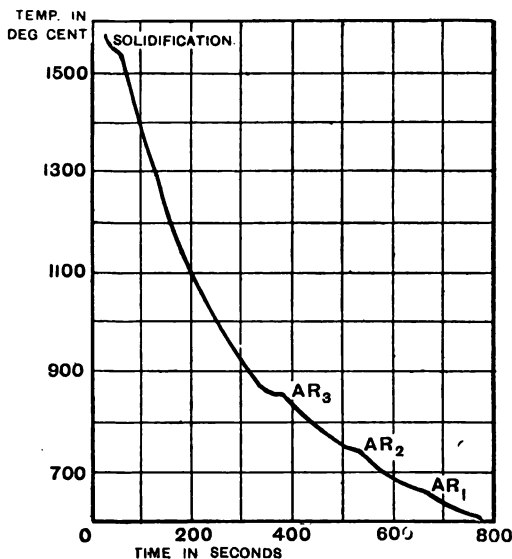
Fig. 105.—Cooling Curve of Pure Iron.

points are indicated by the letters Ar_1, Ar_2, Ar_3; Ar_1 being
that at the lowest temperature, and Ar_3 that at the
highest. As steels higher and higher in carbon are ex-
amined, the three points are still noticed, but the
temperatures at which the retardations Ar_2, Ar_3 occur
are lower and lower, that is, they approach nearer to
the Ar_1 point; till at last, when a steel with over 1 per
cent. of carbon is reached, the three points coincide, and
the long retardation, which produces the recalescence,
is the result. (Figs. 105 and 106.)

Passing in the other direction, *i.e.* towards pure iron, by steels containing less and less carbon, the three points become further separated, and the retardation at Ar_1 becomes less and less, till with pure iron Ar_3 is about 860° C., Ar_2 about 750° C., while Ar_1 has disappeared. (Fig. 105.) If the change at Ar_1 be due to a change in the condition of the carbon, it is obvious that it must disappear when there is no carbon to change. When a steel is cooled slowly, the changes which take place at these critical points, whatever they may be, are more or less complete. When, however, the cooling is very rapid, the
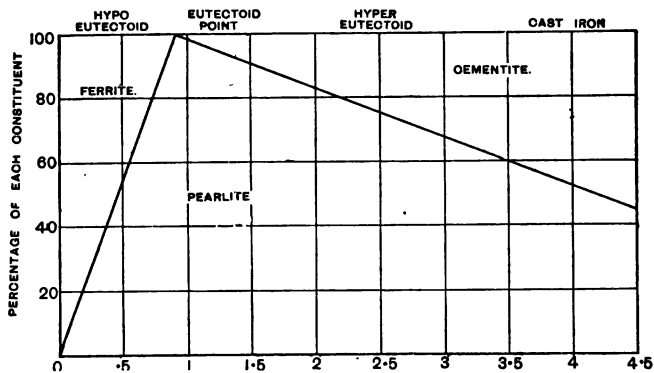
Fig. 106.—Percentage of Combined Carbon.

change cannot take place, or, at least, can only take place very partially, and the iron is retained in the condition which it had above the point of cooling. Hence we should expect that the properties of the metal would be different according as the quenching was above any one of the critical points. In ordinary carbon steel the point Ar_1 is about 690°, so that if the steel is to be kept hard, it must be quenched from above that temperature, but the addition of certain constituents such as tungsten-nickel and other elements may lower the Ar_1 point to the atmospheric temperature or even to 0° C., and steels are thus produced which do not need quenching, but harden on cooling in air, and which are, therefore, called self-hardening steels. Such steels will retain a cutting edge

at a much higher temperature than ordinary carbon steels, and are, therefore, largely used for tools.

The Allotropic Theory of Steel.—As in the cooling of pure iron there are changes which lead to a retardation of the cooling, these must be due to changes in the iron itself, and the theory generally held now is that the changes are the passage of the iron from one ·allotropic condition to another.

Students of chemistry will be familiar with the fact that many elements can exist in allotropic modifications. For instance, carbon as the diamond and graphite; phosphorus as ordinary yellow and red phosphorus; sulphur in at least four allotropic modifications, whilst allotropic modifications of tin and other metals are known. As a rule, each modification is stable only within certain limits of temperature, and on passing from the one range of temperature to another the body will change its allotropic condition provided the temperature change be slow enough, but as some of the changes take place very slowly, the element may be retained wholly or partially in the condition which belongs to the higher temperature. Thus when sulphur is crystallised from fusion, it occurs in transparent yellow needles of what is called prismatic or β sulphur. After a time the crystals, whilst retaining their form, become opaque. The reason is that β sulphur is only stable above 96° C., below that it gradually passes over into α or octohedral sulphur. As, owing to the rigidity of the solid, the outer form of the crystals cannot change, the change is only molecular, but this, by breaking up the interior structure of the crystals, makes it opaque.

The allotropic theory of steel assumes that iron can exist in three allotropic modifications, indicated by the Alpha (α), Beta (β), and Gamma (γ) iron. The student must remember that this is only a theory, and is not by any means proved, but the language of the theory has been so largely adopted that it must be understood. Alpha iron is the ordinary form of iron, stable at temperatures below about 690°; it is soft and ductile, and is magnetic. Beta iron is stable only between temperatures of 700° to 860°; it is hard, brittle, and non-magnetic. Gamma iron is stable at temperatures above 800° C.; it is hard, ductile, and non-magnetic.

When a piece of mild steel solidifies from fusion it is in the form of γ iron; at about 820° it passes into β iron, this change causing the first retardation; at about 730° it passes into the condition of α iron, thus causing the second retardation; and at about 690° the carbon passes into the condition of pearlite. With a high carbon steel the point Ar_1 is gradually lowered, till at last the β form is eliminated, the γ iron passes at once into α iron, and the carbon passes from the martensite to the cementite (pearlite) form, all the changes taking place at the same time.

The critical point in the case of a high carbon steel slowly cooled will be attended with this double change, the passage of the iron from the γ to the α form, and the change in the condition of the carbon. Sudden quenching may retard one or both of these changes, and the question arises, to the retardation of which change is the hardness of hardened steel due? Is it due to the retention of the iron in the γ condition, or the retention of the carbon in the martensite condition? According to the allotropic theory, it is the former; according to the carbon theory, it is the latter.

At first sight it would seem that if the allotropic theory is true, it ought to be possible to harden pure iron by quenching, which certainly cannot be done. To this it is replied that in the case of pure iron the changes take place so rapidly that it is impossible to retain the metal in the γ and β condition, however rapid the cooling may be, but that carbon retards the change, and therefore retains the iron in the hard form, and that other elements have the same effect to a still more marked degree.

Ordinary steel loses its magnetic properties when heated over Ar_1, both β and γ iron being non-magnetic, or, to put it in another way, steel only becomes magnetic when it has cooled sufficiently to allow the iron to pass into the α condition.

If a steel be made containing 8 per cent. of manganese, it is non-magnetic, and, on cooling, shows no retardation or break in the cooling curve, the explanation being that the manganese retards the passage of the iron into the α form, and therefore retains it as γ iron. This alloy is excessively hard. At very low temperatures, if cooled,

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` for instance, in liquid air, the alloy does become magnetic, the critical point being therefore very low.

Certain alloys of iron and nickel (about 36 per cent. nickel) do not expand on heating, the explanation being : the passage from γ to a iron first begins at ordinary temperatures, and a iron occupies a greater volume than γ iron, so that as the change takes place the contraction by cooling is just balanced by the increase in volume due to the change in the condition of the iron, and similarly expansion on heating will be balanced.

It must always be borne in mind that the change from one condition to another is not instantaneous, but takes time, and therefore does not take place sharply at one temperature, but extends over a considerable range, the critical points being simply the points when the change is most marked, it beginning a little above and being continued a little below this temperature.

Professor Arnold does not accept the allotropic theory, and proposes in place of it a solution—a subcarbide theory—which explains most of the facts.

With saturated or eutectoid steel, containing ·89 per cent. of carbon, there is only the one change, the passage of Martensite (in this case Hardenite, which Arnold regards as a subcarbide, $Fe_{24}C$) into pearlite.

With saturated steel containing, say, ·9 per cent. of carbon, on heating at Ar_1, the pearlite passes into hardenite, so that on quenching above Ar_1 the structure is but little changed, the hardenite areas simply replacing the pearlite areas. At Ar_2 the hardenite dissolves in the ferrite, forming a Martensite lower in carbon than Hardenite, and at Ar_3 there is an expansion similar to the expansion of water at 4° C.

With hyper-eutectic steels, say 1·4 per cent. carbon, the pearlite changes into hardenite at about 700° C., and at a higher temperature the cementite dissolves in the Hardenite, forming a higher carbon Martensite.

The table will show at a glance the condition of things according to the two theories.

Solidification of Steel.—When steel, like any other solid, solidifies from fusion it tends to form crystals. These crystals are cubic, but as they grow they tend to press upon one another, and thus destroy the regularity

	Carbon Theory.	Allotropic Theory.	Microstatics.
Above Ar₃ ...	Solution of Hardenite in iron	Solution of carbon in γ iron	Very mild steel, Martensite or ferrite.
Change at Ar₃	Maximum density of solution	Passage of γ iron to β iron	Separation of a certain amount of ferrite previously included in Martensite.
Between Ar₂ and Ar₃	Solution of Hardenite in iron	Solution of carbon in β iron	Soft or medium hard steel made up of martensite and ferrite.
Change at Ar₂	Segregation of carbide Fe₂₄C	Passage of β iron into α iron	Separation of more ferrite from Martensite.
Between Ar₂ and Ar₁	Segregated Hardenite	Solution of carbon in α iron	Soft steel Martensite and ferrite. Hard steel Martensite and cementite.
Change at Ar₁	Hardenite passes into pearlite, *i.e.* Fe₂₄C = Fe₃C + 21Fe	Separation of Fe₃C and formation of pearlite	Disappearance of Martensite and appearance of pearlite.
Below Ar₁ ...	Pearlite with either ferrite or cementite	Pearlite with either ferrite or cementite	Soft steel pearlite and ferrite. Hard steel pearlite and cementite.
Cause of hardening...	Retention of the carbon as Hardenite	Retention of the iron in its hard allotropic condition	Retention of Martensite.

of form, producing a granular structure, each grain being in reality a crystal (allotriomorphic crystal), and sometimes showing a distinct cleavage. If the solution does not crystallise as a whole, but contains foreign matter, this will be ejected, and will often solidify along the lines separating the crystals.

Changes after Solidification.—Many changes may take place after solidification, whilst the metal is in a soft condition, the principal changes being of the nature of diffusion and segregation.

If the metal be maintained at a high temperature after solidification, the constituents which had segregated may to a certain extent diffuse, and this long annealing may tend to equalisation of composition. At a high temperature also there is great freedom among the molecules, so that the crystals tend to still further develop, the larger crystals encroaching upon and absorb-

ing the smaller ones, and this producing a coarse-grained structure. As the strength of a metal is usually the greater the finer the crystal structure, heating to a high temperature for a considerable time tends to increase the size of the crystal grains, and thus weaken the metal. The factor time plays an important part, since these changes of aggregation are comparatively slow.

The coarseness or fineness of the structure can be determined by examination under the microscope. The appearance of an actual fracture is sometimes a guide as to the quality of the metal, but it varies so much with the way in which the fracture has been made that it is of little value except in extreme cases.

The Grain of Steel.—As a rule, the higher the temperature to which the metal has been heated the coarser will be the grain, and the grain size will not be modified by the subsequent cooling or by changes in the constitution of the metal. Thus the passage from martensite to pearlite will not alter the grain form, as the change will take place within each crystal grain. For every temperature with a given quality of steel there is what may be called a normal grain size. If the grains be smaller they will gradually grow until they acquire the normal size, but if they are larger they will not shrink. It follows, therefore, that as the higher the temperature the larger the grains, that the size of the grains will be determined by the highest temperature to which the metal has been heated.

The grain of a piece of cold steel depends, therefore, on the temperature to which it has been heated. If now the cold steel be heated to just above the critical points, Ar_1, Ar_2, Ar_3, say 900°, the crystal grain structure, whether large or small, is completely broken up, and is replaced by an extremely fine grain. This is called heat refining, and is now largely used for the improvement of steel. Care must, of course, be taken that the temperature be not too high, or large crystal grains may again be produced. The temperature which is required for the heat refining seems to be that at which the magnetism of the iron disappears.

In the case of very low carbon steels, Stead found that the size of the crystal grains increases as the steel is heated to about 700° C., but that on heating to Ar_3

(900°) the coarse structure is completely broken up, and a fine grain is produced.

Burnt Steel.—If a steel be very much overheated it becomes burnt (Fig. 107), and then cannot be restored by heat refining. The grains become very large and partially separate, owing probably to the evolution of gas. Such steels are extremely brittle, both hot and cold, and break with a bright, shining fracture. Very often air finds its

Fig. 107.—Burnt Steel.

way in, and a film of oxide is formed between the separated grains.

Effect of Work.—Hammering, rolling, and similar work tends to break down the coarsely crystalline structure of steel, and thus to greatly improve its quality. The grains become distorted, and then break up and rearrange themselves into fresh and smaller grains, the grain size approximating to that due to the temperature at which they are actually formed, the work setting up a state of stress which facilitates rearrangement, and the grain will be smaller the lower the temperature at which the rolling is finished, and therefore finishing at a high temperature will tend to produce a coarse-grained, brittle steel.

Sorbitic Steel.—The rate of cooling of steel, as already remarked, has a great influence on its character. We have so far distinguished two classes of steel, that which has

been hardened by chilling in which the carbon is present as martensite, and that which has been cooled very slowly or annealed, in which the carbon is present as pearlite, each of these varieties having its own good qualities. There is, however, an intermediate condition in the sorbitic steels—*i.e.* those which contain sorbite—and these have valuable properties of their own.

If sorbite be an intermediate stage between hardenite and pearlite, or if it be unsegregated pearlite, it is easy to understand that a metal in which the hard and soft constituents are very finely distributed might be stronger than one in which they have segregated into definite plates. It is also easy to see that such a condition may be obtained by heat treatment, either by cooling from the martensite condition at such a rate that whilst the hardenite will break up into ferrite and cementite, these will not have time to segregate into the plates of pearlite, or by heating in such a way that the pearlite will break up but not pass into hardenite. Sorbitic steels are now largely made.

Stead gives an instance of a steel with 0·35 per cent. of carbon which was quenched from 800°—*i.e.* just above Ar_2—and was then reheated to 650°—*i.e.* just below Ar_1—with the following results :—

	Normal.	Treated.
Breaking weight	42·2 tons ...	51·1 tons.
Elongation on 2 inches ...	23 per cent. ...	23 per cent.
Contraction of area ...	36·1 ,, ...	38 per cent.

" The heated steel contained much unsegregated pearlite or sorbite; indeed, it was difficult to detect cementite in the pearlite areas."

In another case Siemens and Boynton give the following particulars of a steel cooled from 1,150° :—

How cooled.	Prevailing constituents.	Elastic limit lb. per sq. in.	Tenacity lb. per sq. in.	tons per sq. in.
In furnace ...	pearlite ...	39,901	81,162	36
In air ...	sorbite ...	55,000	99,972	45

CHAPTER XV.

STEEL, as already pointed out, varies very much in character according to its composition and the treatment to which it has been subjected, and as for every purpose for which steel can be required there are some properties which are essential, or, at least, very important, the engineer specifies certain tests or conditions which the metal must pass before it will be accepted, and it is the business of the steel maker to produce a steel which will conform to the required specification.

Chemical Analysis.—Since the grade of the steel is fixed by its chemical composition, chemical analysis is of the utmost importance. As there are impurities, such as silicon, sulphur, and phosphorus, the presence of which, if not absolutely injurious, is certainly not advantageous, and yet the entire absence of which cannot be guaranteed, a limit is fixed to the amount which will be allowed.

The grade of the steel depends upon the amount of carbon present. The higher the carbon in general the greater the tensile strength but the less the ductility, and it often happens that ductility is of more importance than tensile strength. The percentage of carbon which the steel contains is therefore given, and at the same time a limit, both upward and downward, is fixed, a carbon higher or lower than which will lead to the rejection of the steel.

Physical Tests and Inspection.—Chemical composition is, however, not by any means all that is necessary, and it is always supplemented by physical tests of various kinds, depending on the purpose for which the metal is to be used, an endeavour being made to apply tests in such a way as to ensure the properties which are of the greatest importance.

In order to see that the work of testing is correctly carried out, that the articles made are perfect, and that any conditions that may be specified as to the method or

condition of manufacture are carried out, an inspector is very frequently sent to the works. In the case of ship plates, for instance, the inspectors from Lloyds, the Bureau Veritas, or other organisation under the authority of which the ship is to be classed, sends its inspector to the works to see that the quality of the metal is up to the required standard.

The ordinary tests which are used for determining the tensile strength—the elongation before fracture, the contraction of area before fracture if required, the yield point, and the modulus of elasticity—have been already described, but there are other tests which are used for special purposes.

Drop Test.—Where an article, as, for instance, an axle or a tyre, will be subjected to shock, it is usually submitted to a drop test. That is, the axle is placed across supports, or the tyre is placed on edge, and a weight is allowed to fall from a height on to it. In the case of axles the falling weight produces a certain deflection. The axle is then turned over, so that the next blow tends to straighten it, and so on; or the axle may be left always in the same position. The falling weight is often 1 ton, and the height of drop depends on the size and strength of the article being tested. The number of blows the axle must stand is specified. In the case of tyres, they will bend nearly flat without fracture, though the test usually specifies that the tyre must stand till it is deflected to one-sixth of its original diameter.

Cold bending tests are also sometimes specified, the piece being bent over cold either till the two halves are in contact—*i.e.* till it has been bent through 180°—or till the two parts are at an angle which varies with the thickness of the test piece. Any sign of fracture at the bend will lead to the metal being rejected.

Hot Tests.—For mild steels to be worked hot, hot tests are sometimes specified, and these are conducted in various ways. The most usual test is to punch a hole through the bar, its diameter being about half the width of the bar. This is then expanded by means of a drift until it is about twice the diameter that the bar is wide. The bar is then cut across at right angles to its length across the diameter of the hole, and the two halves are hammered back. The

test may be varied almost indefinitely, the object being to make sure that the metal will not crack when worked hot. Sometimes the welding capacity of the metal is tested by welding two pieces together and then subjecting the welding portion to hot and cold bending tests.

Brittleness.—This may be tested by bending a test piece of the metal through a very small angle rapidly in opposite directions, at the rate of 1,000 or more per minute, by means of a suitable machine. The number of alternations required to produce fracture will depend upon the character of the steel and the treatment to which it has been subjected. The following figures from an experiment of Mr. Stead's will illustrate the effect of treatment :—

					Vibrations required to produce fracture.
Steel carbon ·44 per cent.	Normal ...	...	...	...	1,432,500
	Overheated	...	...	...	844,950
	Reheated ...	...	...	...	2,080,440
	Annealed ...	...	...	...	1,971,000
	Sorbitic ...	...	...	...	3,517,200

Other Tests.—Other tests have been suggested as giving valuable indications as to the quality of the metal, but have not come into use commercially :—

Microscopic Structure.—Examination of microscopic sections of metal is very valuable for many purposes, but is not commercially specified.

Selecting the Test Piece.—The part of the process at which the samples for testing will be taken will, of course, depend on the nature of the article being made, but the rule always is that the sample should be taken as near the completion of the processes of manufacture as possible.

In the case of ship and similar plates a sample is taken from each sheet as rolled; in the case of castings either a sample of the metal is taken as cast, or, if possible, a sample is cut out of the casting itself, and in the case of forgings similarly a sample is cut out. Obviously the sample must be taken from such a position as to be a fair sample of the metal, so that it must not be taken from portions that are cut off and rejected.

In the case of drop and similar tests, where the whole article is tested and is of no further use, a certain proportion are selected at random, and if these fail the whole batch from which they come is rejected.

Standard Tests.—It is very important that all users of similar material for similar purposes should require the same tests, great and unnecessary trouble being given to the steel maker by variations in specification for similar purposes. In this country each engineer draws up his specification, and it therefore often happens that two engineers will insist on different tests for steel for exactly the same purposes.

In August, 1901, the American Section of the International Association for Testing Materials drew up a series of standard specifications, which have been largely followed.

The specifications deal with :—

(1.) Process of manufacture. (2.) Chemical .properties. (3.) Physical properties. (4.) Test pieces and methods of testing. (5.) Finish and variation in weight. (6.) Branding. (7.) Inspection.

The steels were divided into nine classes, and the following table gives the particulars as to the processes to be used :—

(1.) Steel castings : Open-hearth, Bessemer, or crucible processes. (2.) Steel axles: Open hearth. (3.) Steel forgings : Open-hearth, Bessemer, or crucible. (4.) Steel tyres: Open-hearth. (5.) Steel rails : Open-hearth or Bessemer. (6.) Steel splice bars: Open-hearth or Bessemer. (7.) Structural steel for buildings : Open-hearth or Bessemer. (8.) Structural steel for bridges and ships: Open-hearth. (9.) Boiler plate and rivet steel: Open-hearth.

It will be noted that for some purposes steel may be made by any of the processes, whilst for others it is restricted to one or two of the' three. No distinction is made between the acid or the basic forms of the processes, but an engineer can specify either should he desire it.

Many engineers specify many details as to the material that is to be used, as, for instance, that the steel is to be made from hæmatite iron, or as to the way in which the process is to be conducted. This is quite unnecessary, and it severely handicaps the steel-maker. The engineer should know exactly what he wants, and how to make the necessary tests to make sure that he gets it ; then he should leave the manufacturer free to produce a suitable material in the best way he can.

Chemical Composition.—The following table gives the limits of the various constituents specified for the different grades of steel :—

Specification for	C.	P.	S.	Mn.	Si.	Ni.
Steel castings { Ordinary ...	not over 0·4	not over 0·08	not over —			
Tested ...		0·05	0·05			
Steel axles { Car, engine, and tender ...		0·06	0·06			
Driving wheel, Carbon steel ...		0·06	0·06			
Nickel steel ...		0·04	0·04			3·0–4·0
Low carbon steel ...		0·10	0·10			
Steel forgings { Carbon steel, not annealed ...		0·06	0·06			
Carbon steel, oil tempered or annealed ...		0·04	0·04			
Nickel steel, oil tempered or annealed ...		0·05	0·05			3·0–4·0
Steel tyres ...		0·05	0·05	not over 0·80	not under 0·20	
Structural steel for buildings, including rivets ...		0·10				
Structural steel for bridges and ships, including rivets { Acid open-hearth ...		0·08	0·06			
Basic open-hearth ...		0·06	0·06			
Boiler plate and rivet steel { Flanges or boiler steel { Acid ...		0·06	0·05	0·30–0·60		
Basic ...		0·04	0·04	0·30–0·60		
Fire-box { Acid ...		0·04	0·04	0·30–0·50		
steel { Basic ...		0·03	0·04	0·30–0·50		
Extra soft steel ...		0·04	0·04	0·30–0·50		
Steel rails— Weight per yard specified { 50 lb. to 59 lb.	0·35–0·45	0·10		0·70–1·00		
60 lb. to 69 lb.	0·38–0·48	0·10		0·70–1·00		
70 lb. to 79 lb.	0·40–0·50	0·10		0·75–1·05		
80 lb. to 89 lb.	0·43–0·53	0·10		0·81–1·03		
90 lb. to 100 lb.	0·45–0·55	0·10		0·80–1·10		
Steel splice bars ...	not over 0·15	0·10		0·30–0·60	not over 0·20	

The carbon is not specified in cases where a tensile strength is required, because the two go together, and because for a definite tensile strength the percentage of carbon will vary somewhat, according to the process by which the steel is made.

Physical Tests.—The physical tests are tensile strength, yield point, and elastic limit, elongation and contraction of area, with cold bending and drop tests, when required. The actual strengths required will vary according to the purpose for which the steel is required.

Test Pieces.—The form and dimensions of the test piece to be shown in Figs. 108 and 109. The test piece to be of
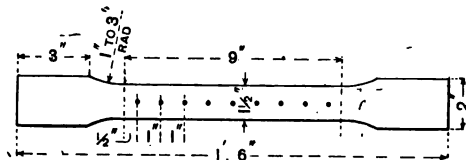
Fig. 108.
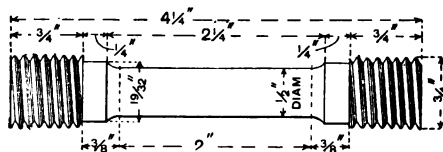
Fig. 109.

Figs. 108 and 109.—Test Pieces.

the thickness of the plate wherever possible, so that the two opposite sides are rolled surfaces, whilst rivet bars, small rolled bars, etc., shall be tested of full size as rolled. For steel forgings a test piece 2 in. long and ½ in. in diameter was recommended, because it is often impossible to cut a large sample out of the casting.

It is not necessary here to discuss the other points, but the standard specifications for steel castings, steel axles, and structural steel for bridges and ships are given as examples.

Steel Castings.—(1.) Steel castings may be made by the open-hearth, crucible, or Bessemer process, and may be annealed or unannealed as specified.

(2.) Ordinary castings, those in which no physical re-
quirements are specified, shall not contain over ·40 per ·
cent. carbon nor over 0·08 per cent. of phosphorus.

(3.) Castings which are subjected to physical test shall
not contain over 0·05 per cent. of phosphorus nor over
0·05 per cent. of sulphur.

(4.) Tested castings shall be of three classes : Hard,
medium, and soft. The minimum physical qualities re-
quired in each class shall be as follows :—

	Hard.	*Medium.*	*Mild.*
Tensile strength, lbs. per square inch ...	85,000	70,000	60,000
Yield point, lbs. per square inch	38,250	31,500	27,000
Elongation per cent. in 2 inches	15	18	22
Contraction of area per cent.	20	25	30

(5.) A test to destruction may be substituted for the
tensile test in the case of small or unimportant castings
by selecting three castings from a lot. This test shall
show the material to be ductile, free from injurious de-
fects, and suitable for the purposes intended. A lot shall
consist of all castings from the same melt or blow, an-
nealed in the same furnace charge.

(6.) Large castings are to be suspended and hammered
all over. No cracks, flaws, defects, nor weakness shall
appear after such treatment.

(7.) A specimen one inch by one-half inch (1 in. by ½ in.)
shall bend around a diameter of one inch (1 in.) without
fracture on outside of bent portion through an angle of
120° for " *soft* " castings and of 90° for " *medium* " cast-
ings.

(8.) The standard turned specimen, one-half inch
(½ in.) in diameter and two-inch (2-in.) gauged length,
shall be used to determine the physical properties specified
in paragraph No. 4. It is shown in Fig. 109.

(9.) The number of standard test specimens shall de-
pend upon the character and importance of the castings.
A test piece shall be cut cold from a coupon, to be moulded
and cast on some portion of one or more castings from
each melt or blow, or from the sink heads (in case heads
of sufficient size are used). The coupon or sink head

must receive the same treatment as the casting or castings before the specimen is cut off, and before the coupon or sink head is removed from the casting.

(10.) One specimen for bending test, one inch by onehalf inch (1 in. by ½ in.), shall be cut cold from the coupon or sink head of the casting or castings, as specified in paragraph No. 9. The bending test may be made by pressure or blows.

(11.) The yield point, specified in paragraph No. 4, shall be determined by the careful observation of the drop of the beam or halt in the gauge of the testing machine.

(12.) Turnings from the tensile specimen, drilling from the bending specimen, or drillings from the small test ingots, if preferred by the inspector, shall be used to determine whether or not the steel is within the limits of phosphorus and sulphur specified in paragraphs Nos. 2 and 3.

(13.) Castings shall be true to pattern, free from blemishes, flaws, or shrinkage cracks. Bearing surfaces shall be solid, and no porosity shall be allowed in portions where the resistance and value of the casting for the purpose intended will be seriously affected thereby.

(14.) An inspector representing the purchaser shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture prior to shipment.

Steel Forgings.—(1.) Steel for forgings may be made by open-hearth, crucible, or Bessemer process.

(2.) There shall be four classes of steel forgings, which shall conform to the following limits in chemical composition :—

	Forgings of soft or low carbon steel.	Forgings of carbon steel not annealed.	Forgings of carbon steel oil-tempered or annealed.	Forgings of nickel steel oil-tempered or annealed.
	per cent.	per cent.	per cent.	per cent.
Phosphorus shall not exceed	0·10	0·06	0·04	0·04
Sulphur shall not exceed	0·10	0·06	0·04	0·04
Nickel	—	—	—	3·00–4·00

(3.) The minimum physical qualities required of the different sized forging of each class shall be as follows :—

Tensile strength.	*Yield point.*	*Elongation in 2 in.*	*Contraction of area.*	
lbs. per sq. in.		per cent.		
58,000	29,000	28	35	Soft steel or low carbon steel for solid or hollow forgings, no diameter or thickness of section to exceed 10 in.
75,000	37,500	18	30	Carbon Steel *not* annealed for solid or hollow forgings, no diameter or thickness of section to exceed 10 in.
80,000	40,000	22	35	Carbon Steel Annealed, for solid or hollow forgings, no diameter or thickness of section to exceed 10 in.
75,000	37,500	23	35	For solid forgings, no diameter to exceed 20 in., or thickness of section 15 in.
90,000	55,000	20	45	Carbon Steel Oil-tempered, for solid or hollow forgings, no diameter or thickness of section to exceed 3 in.
85,000	50,000	22	45	For solid forgings of rectangular sections not exceeding 6 in. in thickness, or hollow forgings the walls of which do not exceed 6 in. in thickness.
80,000	45,000	23	40	For solid forgings of rectangular sections not exceeding 10 in. in thickness, or hollow forgings the walls of which do not exceed 10 in. in thickness.
80,000	50,000	25	45	Nickel Steel Annealed, for solid or hollow forgings, no diameter or thickness of section to exceed 10 in.
80,000	45,000	25	45	For solid forgings, no diameter to exceed 20 in. or thickness of section 15 in.
80,000	45,000	24	40	For solid forgings over 20 in. diameter.
95,000	65,000	21	50	Nickel Steel Oil-tempered, for hollow or solid forgings, no diameter or thickness of section to exceed 3 in.
90,000	60,000	22	50	For solid forgings of rectangular sections not exceeding 6 in. in thickness, or hollow forgings the walls of which do not exceed 6 in. in thickness.
85,000	55,000	24	45	For solid forgings of rectangular sections not exceeding 10 in. in thickness, or hollow forgings the walls of which do not exceed 10 in. in thickness.

(4.) A specimen, one inch by one-half inch (1 in. by

½ in.), shall bend cold 180° without fracture on outside of bent portion as follows around a diameter of ½ in. for forgings of soft steel; around a diameter of 1½ in. for forgings of carbon steel not annealed; around a diameter of 1½ in. for forgings of carbon steel if 20 in. in diameter or over; around a diameter of 1 in. for forgings of carbon steel annealed if under 20 in. in diameter; around a diameter of 1 in. for forgings of carbon steel oil-tempered; around a diameter of ½ in. for forgings of nickel steel annealed; around a diameter of 1 in. for forgings of nickel steel oil-tempered.

(5.) The standard turned test specimen, one-half inch (½ in.) diameter and two inch (2 in.) gauged length, shall be used to determine the physical properties specified in paragraph No. 3. It is shown in Fig. 109. Number and location of tensile specimens :—

(6.) The number and location of test specimens to be taken from a melt, blow, or a forging shall depend upon its character and importance, and must therefore be regulated by individual cases; the test specimens shall be cut cold from the forging, or full-sized prolongation of same parallel to the axis of the forging, and halfway between the centre and outside the specimens to be longitudinal— *i.e.* the length of the specimen to correspond with the direction in which the metal is most drawn out or worked. When forgings have large ends or collars, the test speci-mens shall be taken from a prolongation of the same diameter or section as that of the forging back of the large end or collar. In the case of hollow shafting, either forged or bored, the specimen shall be taken within the finished section prolonged half way between the inner and the outer surface of the wall of the forging.

(7.) The specimen for bending test, one inch by one-half inch (1 in. by ½ in.), shall be cut as specified in paragraph No. 6. The bending test may be made by pressure or by blows.

(8.) The yield point, specified in paragraph No. 3, shall be determined by the careful observation of the drop of the beam or halt in the gauge of the testing machine.

(9.) The elastic limit, specified in paragraph No. 3, shall be determined by means of an extensometer, which is to be attached to the test specimen in such a manner as to show

the change in rate of extension under uniform rate of loading, and will be taken at that point where the proportionality changes.

(10.) Turnings from the tensile specimen or drillings from the bending specimen, or drillings from the small test ingot, if preferred by the inspector, shall be used to determine whether or not the steel is within the limits in chemical composition specified in paragraph No. 2.

(11.) Forgings shall be free from cracks, flaws, seams, or injurious imperfections, and shall conform to dimensions shown on drawings furnished by the purchaser, and be made and finished in a workmanlike manner.

(12.) The inspector representing the purchaser shall have all the reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture prior to shipment.

Steel Rails.—(1.) (*a*) Steel may be made by the Bessemer or open-hearth process. (*b*) The entire process of manufacture and testing shall be in accordance with the best standard current practice, and special care shall be taken to conform to the following instructions; (*c*) Ingots shall be kept in a vertical position in pit-heating furnaces; (*d*) no bled ingots shall be used; (*e*) sufficient material shall be discarded from the top of the ingots to insure sound rails.

(2.) Rails of various weights per yard, specified below, shall conform to the following limits in chemical composition :—

	50 to 59 + pounds. Per cent.	60 to 69 + pounds. Per cent.	70 to 79 + pounds. Per cent.	80 to 89 + pounds. Per cent.	90 to 100 pounds. Per cent.
Carbon	0·35–0·45	0·38–0·48	0·40–0·50	0·43–0·53	0·45–0·55
Phosphorus shall not exceed	0·10	0·10	0·10	0 10	0·10
Silicon shall not exceed	0·20	0·20	0·20	0·20	0·20
Manganese	0·70–1·00	0·70–1·00	0·75–1 05	0·80–1·10	0·80–1·10

(3.) One drop test shall be made on a piece of rail

N

not more than 6 ft. long, selected from every fifth blow
of steel. The rail shall be placed head upwards on the
supports, and various sections shall be subjected to the
following impact tests :—

Weight of rail.				Height of drop.
Pounds per yard.				Feet.
45 to and including 55	...	...		15
More than 55 ,, ,, 65	...	...		16
,, 65 ,, ,, 75	..	...		17
,, 75 ,, ,, 85	...	...		18
,, 85 ,, ,, 100	...	...		19

If any rail break when subjected to the drop test, two
additional tests will be made of other rails from the same
blow of steel, and if either of these latter tests fail, all
the rails of the blow which they represent will be rejected;
but if both of these additional test pieces meet the re-
quirements, all the rails of the blow which they represent
will be accepted. If the rails from the tested blow shall
be rejected for failure to meet the requirements of the
drop test as above specified, two other rails will be sub-
jected to the same tests, one from the blow next preceding
and one from the blow next succeeding the rejected blow.
In case the first test taken from the preceding or succeed-
ing blow shall fail, two additional tests shall be taken
from the same blow of steel, the acceptance or rejection
of which shall also be determined as specified above; and
if the rails of the preceding or succeeding blow shall be
rejected, similar tests may be taken from the previous or
following blows, as the case may be, until the entire group
of five blows is tested, if necessary. The acceptance or the
rejection of all the rails from any blow will depend upon
the result of the tests thereof.

(4.) The drop test machine shall have a tup of two
thousand pounds (2,000 lb.) weight, the striking face of
which shall have a radius of not more than five inches
(5 in.), and test rail shall be placed head upwards on
solid supports three feet (3 ft.) apart. The anvil block
shall weigh at least twenty thousand pounds (20,000 lb.),
and the supports shall be a part of, or firmly secured to,

the anvil. The report of the test shall state the atmospheric temperature at the time the tests were made.

(5.) The manufacturer shall furnish the inspector, daily, with carbon determinations of each blow, and a complete chemical analysis every twenty-four hours, representing the average of the other elements contained in the steel. These analyses shall be made on drillings taken from a small test ingot.

(6.) Unless otherwise specified, the section of the rail shall be the American standard, recommended by the American Society of Civil Engineers, and shall conform, as accurately as possible, to the template furnished by the railroad company, consistent with paragraph No. 7, relative to specified weight. A variation in height of one sixty-fourth of an inch ($\frac{1}{64}$ in.) less and one thirty-second of an inch ($\frac{1}{32}$ in.) more. A perfect fit of the splice bars, however, shall be maintained at all times.

(7.) The weight of the rails shall be maintained as nearly as possible, after complying with paragraph No. 6, to that specified in contract. A variation of one half of one per cent. ($\frac{1}{2}$ %) for an entire order will be allowed. Rails shall be accepted and paid for according to actual weights.

(8.) The standard length of rails shall be thirty feet (30 ft.). Ten per cent. (10 %) of the entire order will be accepted in shorter lengths, varying by even feet down to twenty-four feet (24 ft.). A variation of one-fourth of an inch ($\frac{1}{4}$ in.) in length from that specified will be allowed.

(9.) Circular holes for splice bars shall be drilled in accordance with the specifications of the purchaser. The holes shall accurately conform to the drawing and dimensions furnished in every respect, and must be free from burrs.

(10.) Rails shall be straightened while cold, smooth on head, sawed square at ends, and, prior to shipment, shall have the burr, occasioned by the saw cutting, removed, and the ends made clean. No. 1 rails shall be free from injurious defects and flaws of all kinds.

(11.) The name of the maker, the month and year of manufacture, shall be rolled in raised letters on the side of the web, and the number of the blow shall be stamped on each rail.

(12.) The inspector representing the purchaser shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture prior to shipment.

(13.) Rails that possess any injurious physical defects or which, for any other cause, are not suitable for first quality, or No. 1 rails, shall be considered as No. 2 rails, provided, however, that rails which contain any physical defects which seriously impair their strength shall be rejected. The ends of all No. 2 rails shall be painted, in order to distinguish them.

Structural Steel for Bridges and Ships.— (1.) Steel shall be made by the open-hearth process.

(2.) Each of the three classes of structural steel for bridges and ships shall conform to the following limits in chemical composition :—

	Steel made by the acid process.	Steel made by the basic process.
	Per cent.	Per cent.
Phosphorus shall not exceed	0·08	0·06
Sulphur shall not exceed...	0·06	0·06

(3.) There shall be three classes of structural steel for bridges and ships, namely : Rivet steel, soft steel, and medium steel, which shall conform to the following physical qualities :— .

TENSILE TESTS.

	Rivet steel.	Soft steel.	Medium steel.
Tensile strength, pounds per sq. in.	50,000-60,000	52,000-62,000	60,000-70,000
Yield point in pounds per sq. in. shall not be less than	½ T. S.	½ T. S.	½ T. S.
Elongation per cent. in 8 in. shall not be less than	26	25	22

(4.) For material less than five-sixteenths inch ($\frac{5}{16}$ in.) and more than three-fourths inch ($\frac{3}{4}$ in.) in thickness, the following modifications shall be made in the requirements for elongation :—(*a.*) For each increase of one-eighth inch ($\frac{1}{8}$ in.) in thickness above three-fourths inch ($\frac{3}{4}$ in.), a deduction of one per cent. (1 %) shall be made from the specified elongation. (*b.*) For each decrease of one-sixteenth inch ($\frac{1}{16}$ in.) in thickness below five-sixteenths inch ($\frac{5}{16}$ in.), a deduction of two and one-half per cent. (2$\frac{1}{2}$ %) shall be made from the specified elongation. (*c.*) For pins made from any of the three classes of steel, the required elongation shall be five per cent. (5 %) less than that specified in paragraph No. 3, as determined on a test specimen, the centre of which shall be one inch (1 in.) from the surface.

(5.) Eye bars shall be of medium steel. Full-sized tests shall show twelve and one-half per cent. (12$\frac{1}{2}$ %) elongation in fifteen feet (15 ft.) of the body of the eye bar, and the tensile strength shall not be less than fifty-five thousand pounds (55,000 lb.) per square inch. Eye bars shall be required to break in the head, and show twelve and one-half per cent. (12$\frac{1}{2}$ %) elongation in fifteen feet (15 ft.) and the tensile strength specified, it shall not be cause for rejection, provided that not more than one-third ($\frac{1}{3}$) of the total number of eye bars tested break in the head.

(6.) The three classes of structural steel for bridges and ships shall conform to the following bending tests, and for this purpose the test specimen shall be one and one-half inches (1$\frac{1}{2}$ in.) wide, if possible; and for all material three-fourths inch ($\frac{3}{4}$ in.) or less in thickness the test specimen shall be of the same thickness as that of the finished material from which it is cut, but for material more than three-fourths inch ($\frac{3}{4}$ in.) thick, the bending test specimen may be one-half inch ($\frac{1}{2}$ inch.) thick. Rivet rounds shall be tested of full size as rolled. (*d.*) Rivet steel shall bend cold $18\bar{0}°$ flat on itself, without fracture on the outside of the bent portion. (*e.*) Soft steel shall bend cold 180° flat on itself, without fracture on the outside of the bent portion. (*f.*) Medium steel shall bend cold 180° around a diameter equal to the thickness of the specimen tested, without fracture on the outside of the bent portion.

(7.) The standard test specimen, of eight-inch (8-in.) gauged length, shall be used to determine the physical properties specified in paragraphs Nos. 4 and 5. The standard shape of the test specimen for sheared plates shall be as shown in Fig. 11. For other material the test specimen may be same as for sheared plates, or it may be planed or turned parallel throughout its entire length, and, in all cases where possible, two opposite sides of the test specimens shall be the rolled surfaces. Rivet rounds and small rolled bars shall be tested of full size as rolled.

(8.) One tensile test specimen shall be taken from the finished material of each melt, but in case this develops flaws or breaks outside of the middle third of its gauged length, it may be discarded and another test specimen substituted therefor.

(9.) One test specimen for bending shall be taken from the finished material of each melt as it comes from the rolls, and for material three-fourths inch ($\frac{3}{4}$ in.) and less in thickness, this specimen shall have the natural rolled surface on two opposite sides. The bending test specimen shall be one and one-half inches ($1\frac{1}{2}$ in.) wide, if possible, and for material more than three-fourths inch ($\frac{3}{4}$ in.) thick the bending test specimen may be one-half inch ($\frac{1}{2}$ in.) thick. The sheared edges of bending test specimens may be milled or planed. (*g.*) The bending test may be made by pressure or by blows.

(10.) Material which is to be used without annealing or further treatment shall be tested for tensile strength in the condition in which it comes from the rolls. Where it is impracticable to secure a test specimen from material which has been annealed or otherwise treated, a full-sized section of tensile test specimen length shall be similarly treated before cutting the tensile test specimen therefrom.

(11.) For the purpose of this specification, the yield point shall be determined by the careful observation of the drop of the beam or halt in the gauge of the testing machine.

(12.) In order to determine if the material conforms to the chemical limitations prescribed in paragraph No. 2 herein, analysis shall be made of drillings taken from a small test ingot.

(13.) The variation in cross section or weight of more than two and a half per cent. ($2\frac{1}{2}$ %) from that specified will be sufficient cause for rejection, except in the case of sheared plates, which will be covered by the following permissible variations :—(h.) Plates $12\frac{1}{2}$ lb. per square foot

Table for allowances for overweight for rectangular plates when ordered to gauge. Plates will be considered up to gauge if measuring not over $\frac{1}{100}$ in. less than the ordered gauge.

The weight of 1 cubic in. of rolled steel is assumed to be 0·2833 lb.

PLATE $\frac{1}{4}$ IN. AND OVER IN THICKNESS.

Thickness of plate. Inch.	Width of Plate.		
	Up to 75 in. Per cent.	75 to 100 in. Per cent.	Over 100 in. Per cent.
$\frac{1}{4}$	10	14	18
$\frac{5}{16}$	8	12	16
$\frac{3}{8}$	7	10	13
$\frac{7}{16}$	6	8	10
$\frac{1}{2}$	5	7	9
$\frac{9}{16}$	$4\frac{1}{2}$	$8\frac{1}{2}$	$8\frac{1}{2}$
$\frac{5}{8}$	4	6	8
Over $\frac{5}{8}$	$3\frac{1}{2}$	5	$6\frac{1}{2}$

PLATES UNDER $\frac{1}{4}$ IN. IN THICKNESS.

Thickness of plate. Inch.	Width of plate.	
	Up to 50 in. Per cent.	50 in. and above. Per cent.
$\frac{1}{8}$ up to $\frac{5}{32}$	10	15
$\frac{5}{32}$,, $\frac{3}{16}$	$8\frac{1}{2}$	$12\frac{1}{2}$
$\frac{3}{16}$,, $\frac{1}{4}$	7	10

or heavier, up to 100 in. wide, when ordered to weight, shall not average more than $2\frac{1}{2}$ per cent. variation above or $2\frac{1}{2}$ per cent. below the theoretical weight. (i.) Plates under $12\frac{1}{2}$ lb. per square foot, when ordered to weight, shall not average a greater variation than the following : Up to 75 in. wide, $2\frac{1}{2}$ per cent. above or $2\frac{1}{2}$ per cent. below the theoretical weight; 75 in. wide up to 100 in. wide,

5 per cent. above or 3 per cent. below the theoretical weight; when 100 in. wide and over, 10 per cent. above or 3 per cent. below the theoretical weight. (*j.*) For all plates ordered to gauge, there will be permitted an average excess of weight over that corresponding to the dimensions on the order equal in amount to that specified in the table on p. —.

(14.) Finished plates must be free frôm injurious seams, flaws, or cracks, and have a workmanlike finish.

(15.) Every finished piece of steel shall be stamped with the melt number, and steel for piers shall have the melt number stamped on the ends. Rivets and lacing steel, and small pieces for pin plates and stiffeners, may be shipped in bundles, securely wired together, with the melt number on a metal tag attached.

(16.) The inspector representing the purchaser shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture prior to shipment.

CHAPTER XVI.

ALLOY STEELS.

THESE are steels, usually low in carbon, to which some other metal or metals have been added, and often differing considerably in properties from the carbon steels. Ternary steels are those containing one metal in addition to the iron and carbon, ·those with two such metals being termed quaternary. Small variations in the percentage of the alloying element frequently produces modifications in the physical character of the steel totally out of proportion to the amount of change in composition, and further variation may be produced by altering in a slight degree the percentage of carbon present.

Ternary steels may be classified according to the effect of the added metal on the critical points of the steel, and the arrangement of the steels in this chapter is based on the following table :—

Metal added.	General effect.	Classes of steel produced.
Manganese ... Nickel ...	Lower the conversion points Ar₁, etc.	Pearlite, martensite, and γ iron.
Chromium ...	Lowers conversion points and double carbide is formed	Pearlite, martensite, and double carbide.
Molybdenum Tungsten ... Vanadium ...	Form a double carbide	Pearlite and double carbide.
Aluminium .. Silicon ...	Separate carbon as graphite	Graphitic and combined carbon.
Cobalt ... Tin ... Titanium ...	Merely dissolve in the iron	Only pearlitic.

The usual method of introducing the required element into the steel is by means of a ferro-compound, rich in the metal, added while the steel is in the ladle, or even whilst it is teeming into the ingot moulds. It is often prefer-
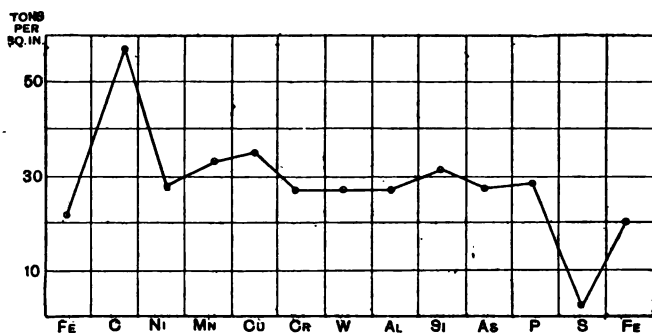
Fig. 110.—Physical Influence of Elements on Iron—Tensile Strength
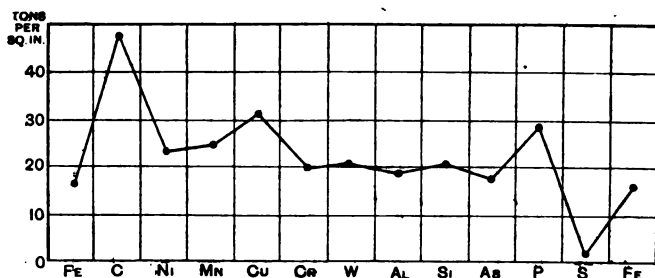
Fig. 111.—Physical Influences of Elements on Iron—Elastic Limit.
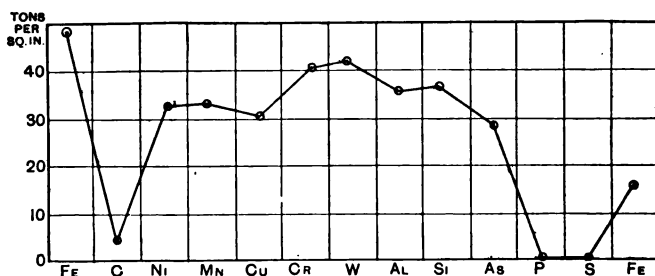
	Fe	C	Ni	Mn	Cu	Cr	W	Al	Si	As	P	S	Fe
Forged		1·35	1·51	1·29	1·81	1·1	1·41	1·85	1·94	1·51	136	·97	Cast.
Car-bon	·04	1·35	·11	·10	·10	·17	·08	·03	·08	·04	·07	·08	·08

[Content.

Fig, 112.—Physical Influences of Elements on Iron—Elongation.

able to make the introduction of the alloy in the furnace, on account of the high melting point of some of the ferro-alloys. Some of the added metal will pass into the slag, but if proper care is taken to keep the slag not too oxidising, only a small proportion is lost in this way.

A general notion of the properties of steels with approximately $1\frac{1}{2}$ per cent. of various alloying elements is shown by the following diagram representing mechanical tests (Figs. 110 to 112).

Manganese Steels.—Manganese is usually added to the molten steel, after it is tapped into the ladle, in the form of ferro-manganese, often containing up to 85 per cent. of manganese. For ordinary steels the ferro-manganese is used for the removal of oxygen from the metal, so that a considerable proportion of the manganese finds its way into the slag, leaving only from ·5 to 1·0 per cent. of manganese in the finished steel. This quantity seems to have almost no influence on the physical properties of the steel, except to counteract the tendency to red-shortness; but as the percentage of manganese approaches 3 per cent., an excessive brittleness shows itself, rendering the metal almost useless; and when 5 to 6 per cent. is reached, the steel is so hard and brittle that it can readily be powdered by crushing. Immediately 7 per cent. of manganese is exceeded, however, an extraordinary physical change takes place, and with from 8 per cent. to 20 per cent. of manganese an alloy known popularly as Hadfield's manganese steel is obtained, possessing very remarkable characteristics.

Manganese, below ·2 per cent., in mild steel makes it difficult to roll or forge, but the malleability returns as the percentage increases. Below ·5 per cent. of manganese content leaves the steel very full of blow-holes, and up to 1 per cent. is required for eliminating these. Above this percentage, the manganese, although increasing the tensile strength, so diminishes the elongation and transverse strength that, when $2\frac{1}{2}$ per cent. is attained, the metal is absolutely rotten through brittleness. Maximum brittleness occurs with the manganese content about 6 per cent., and towards $6\frac{1}{2}$ per cent. a small increment of strength occurs, but the transverse strength still does not exceed that of a good cast iron (12 tons per sq. in.). Hammering

and forging considerably augment the tensile strength, but not enough to render the steel useful commercially.

Very different are the properties of the metal so soon as 7·5 per cent. of manganese is present. Not only do the brittleness and excessive hardness begin to vanish, but the elongation is considerably increased, until, when 10 per cent. of manganese is reached, the most easily machined of this series of alloys is obtained. The most frequently

Analysis.		Unannealed.		Annealed to yellow heat, then			
Per cent.		T.S.	Σ	Air cooled.		Water quenched.	
C.	Mn.	Tons per sq. in.	Per cent.	T. S.	Σ.	T. S.	Σ.
·2	·83	31	31	—	—	—	—
·4	2·3	56	6	—	—	—	—
·5	6·95	25	2	21	2	23	2
·6	7·5	39	4	—	—	—	—
·95	10·11	38	5	39	14	—	—
1·1	12·6	39	2	37	11	54	27
·92	12·81	39	5	48′	20	61	37
·85	14·01	36	2	48	14	67	44
1·24	15·06	49	2	47	2	61	31
2·1	21·69	39	9	34	12	—	—

Fig. 113.—Table of Mechanical Tests made with Manganese Steels.

NOTE :—Throughout this chapter the figures given in the various tables are in standard units, viz. : Tensile Strength [T.S.] in tons per square inch ; Elastic Limit [E.L.] in tons per square inch ; Elongation [Σ.] percentage ductility ; Contraction [C.] percentage reduction of area.

made alloy, however, contains approximately 13 per cent. of manganese with an accompanying 1 per cent. of carbon ; such a steel giving, after being water quenched, the remarkable average tensile strength of 65 tons per sq. in., and about 50 per cent. elongation. This latter extraordinary figure requires explanation, in so far as it is not in strict comparison with the elongation of a carbon steel. The ordinary steel " necks " before fracture, and only at this contracted region does considerable elongation take place, but manganese steels " neck " very little,

the elongation being more uniformly distributed over the whole length of the test piece.

Apart from the peculiar property of being almost completely non-magnetic, manganese steel is perhaps most remarkable for the changes ´it shows when subjected to varying heat treatment, as shown by the undernoted
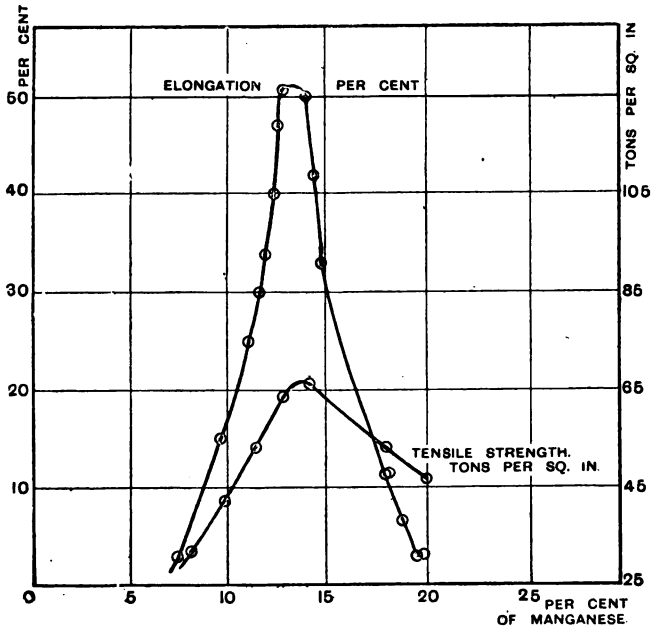
Fig. 114.—Effect of Manganese on Tensile Strength and Elongation of Water-quenched Steel.

table of mechanical tests also shown graphically (Figs. 113 and 114).

It will thus be seen that the use of manganese steel is likely to be restricted on account of the difficulty of machining and filing it, but it can be partially softened by treatment in the.following manner : The tool is heated to very little over 1,000° C., and suddenly quenched in cold water nearly at the freezing point, when the metal

becomes soft enough to be easily filed or even planed.
To restore the former hardness, reheating to a bright
red heat (say 1,000° C.) and slowly cooling it in air is
sufficient. This property of toughening without quench-
ing is known as "self-hardening" (see also Tungsten
Steel).

For high manganese steels with upwards of 12 per cent.
manganese (carbon about 1 per cent.), a very great in-
crease in both tensile strength and the ductility may be
got by heating almost to a white heat (say 1,200° C.) and

Analysis.		Unannealed.				Annealed.			
Per cent.		Tons per sq. in.		Per cent.		Tons per sq. in.		Per cent.	
C.	Ni.	T. S.	E. L.	Σ.	C.	T. S.	E. L.	Σ.	C.
·19	·27	31	19	35	56	28	20	37	52
·14	·51	30	20	36	62	27	21	41	63
·13	·95	33	25	31	53	27	20	41	63
·14	1·92	34	26	33	55	31	22	36	53
·19	3·82	37	28	30	54	33	25	35	55
·18	5·81	41	28	27	40	37	28	33	51
·17	7·65	49	31	26	42	45	30	26	41
·16	9·51	85	42	9	18	56	32	2	2
·18	11·39	94	65	12	24	89	45	12	26
·23	15·48	94	55	3	2	68	—	1	1
·19	19·64	91	47	7	6	87	45	5	4
·16	24·51	77	32	13	14	78	25	14	8
·14	29·07	38	25	33	44	37	16	48	51

Fig. 115.—Table of Mechanical Tests made with Nickel Steel.

then quenching suddenly, care being taken not to have
too large forgings, or else there will be a tendency for the
metal to crack.

One peculiarity of manganese steel is that, on cooling,
the curve obtained is a continuous one, without re-
tardation, which is to say there is no recalescence
observable.

The main use of manganese steel is confined to pur-
poses where extreme hardness is necessary, such as the
working faces of crushing mills and grinding machinery.
Car wheels, also tram and railway crossings, are fre-
quently made of this alloy. For the high resistance coils
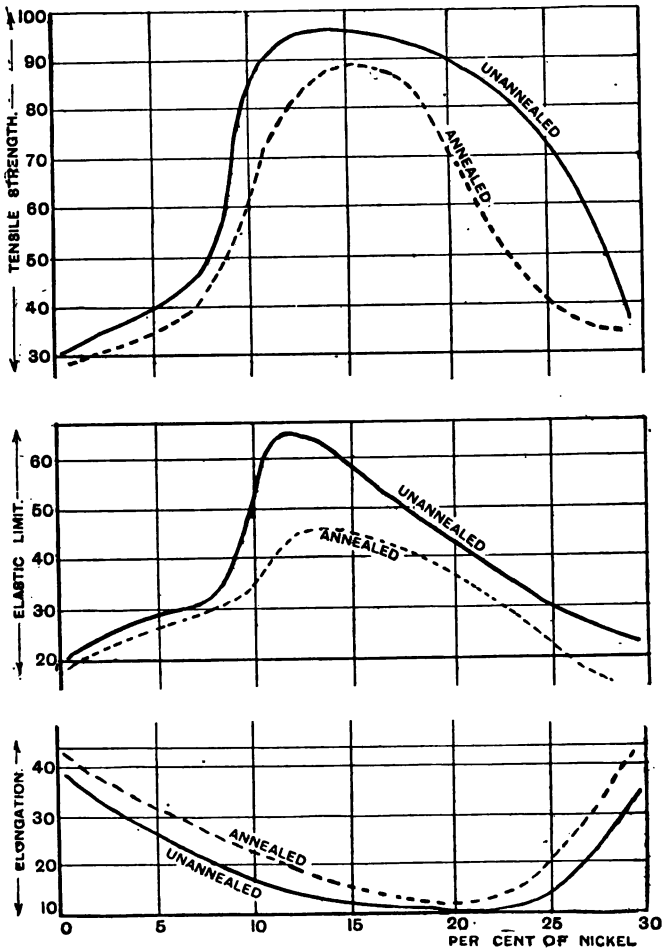
Fig. 116.—Graph of Nickel Steel Properties.

in electrical apparatus it is sometimes employed. Safes
made of manganese steel cannot have the "temper
drawn" by means of the blow-pipe, so that drilling,

preliminary to blasting, is impossible. Very satisfactory razors and axes have been made from a Hadfield steel containing 13·75 per cent. manganese and ·85 per cent. of carbon; this alloy, after forging and water toughening, gave, on testing, a tensile strength of 65 tons per sq. in. and almost 51 per cent. elongation.

Nickel Steel.—Nickel steel is always prepared by adding the nickel to the molten steel in the furnace, since its high melting point (about 1,650° C.) precludes its addition to the metal in the ladle. Small proportions of carbon perceptibly lower the melting point of the steel, so that it can readily be remelted in crucibles to ensure a homogeneous alloy.

The general effect of nickel is to increase the strength of the steel as well as the ductility, imparting at the same time considerable toughness. Nickel very materially alters the physical properties of steel, as seen from the table of mechanical tests and graphs (Figs. 115 and 116).

Up to about 20 per cent. of nickel the tensile strength and elastic limit vary directly with the increase of nickel content, the elongation falling away at the same time, most noticeably after 15 per cent. is exceeded; but with over 20 per cent. of nickel the strength falls away and the elongation increases abnormally, up to about 30 per cent. of nickel. Approximately, 3·5 per cent. of nickel has the same effect as ·2 per cent. of carbon on the tensile strength of steel, but the elastic limit and the ductility are slightly better in the nickel steel. The influence of nickel is not much affected by low carbon percentages, but as the latter increases there is a marked effect, especially in lowering the elastic limit and in increasing the power of hardening on quenching.

The most important characteristic of nickel steel is its high vibrating strength, that is, the power of resisting without fracture a large number of alternating stresses well within the breaking strength. Mild steel, suitably annealed, can be made to stand about 100,000 applications of pressure without rupture, whereas a similar bar of 5 per cent. nickel steel, with low carbon content, will stand about ten times as many alternations. Impact tests show nickel steels to have a high degree of rigidity and toughness; for example, a 3 per cent. nickel steel only

gave about 48 per cent. of the deflection of a correspond-
ing carbon steel, and the number of blows required to
produce rupture was 45 per cent. greater.

Nickel behaves on steel under heat treatment much the
same as carbon does. Thus, nickel alone, in the absence
of carbon, gives steel the power of hardening and acquir-
ing increased strength on quenching, and in presence of
carbon this power is much augmented.

When cooled from high temperatures, nickel steels
give apparently only one recalescence point, and that at
a very considerably lower temperature than ordinary
carbon steel, so that the annealing temperature has to be
kept lower than for ordinary carbon steel, and the nickel
steel will harden on quenching from a much lower tem-
perature.

The hardening effect of quenching nickel steel ceases
when about 10 per cent. of nickel is present, although this
property is quite marked when the percentage is lower.
With between 10 per cent. and 20 per cent. nickel, neither
quenching nor annealing exerts any effect, but above 20
per cent. nickel content the quenching distinctly softens
the alloy, and this weakening effect is very decided at
30 per cent. nickel content.

Nickel, like aluminium, tends to check segregation
in steel, as shown by the fine grain of nickel steel, an
effect probably due to double carbides of high melting
point being formed, thereby causing the whole mass in the
ingot to set almost simultaneously. Nickel does not pre-
vent blow-holes, and this is one of the great difficulties of
the nickel steel maker, since, if these once form, they
do not readily weld up on rolling. Nickel under 1 per
cent. does not appear to affect the welding properties of
the steel, but above this the welding becomes more diffi-
cult, although, even with 3 per cent. of nickel in the steel,
good results can be obtained with care. The tenacity with
which the film of oxide adheres to the surface of the
metal does undoubtedly interfere seriously with the weld-
ing, and this difficulty is increased with increasing per-
centage of nickel.

The magnetic properties of nickel steel are very pecu-
liar; thus, 25 per cent. nickel steel shows no magnetic
properties until cooled down to $-40°$ C., and then it re-

o

mains magnetic at ordinary temperatures. When heated
to 600° C., however, the original non-magnetic state re-
turns. This phenomenon is known as non-reversible trans-
formation, and is possessed to a greater or less degree
by nickel steels containing 25 per cent. or under. It may
be defined as the capability of existing at ordinary tem-
peratures in two different states, characterised by the ap-
pearance or disappearance of magnetism, and, moreover,
when magnetic, possessing higher tensile strength and
lower elongation than when non-magnetic. Chromium is
often added to assist in lowering the irreversible trans-
formation point, as shown by the following results of
recent research on the mechanical properties of two simi-
lar alloys :—

Physical state.	Analysis. Per cent.				Tons per sq. in.		Per cent.	
	C	Mn	Cr	Ni	T S	E L	Σ	C
Magnetic	·16	·13	—	15 92	56½	48½	19	54 5
Non-magnetic ...	·53	·83	3·02	16·05	49	21	73	68·0

The difference in the elongation is most remarkable, as
shown by the illustration from a recent work (Fig. 117).
It will be noticed that the magnetic steel undergoes de-
formation only at the point of fracture, and remains for
the greater part of its length as bright as when turned,
whereas the non-magnetic variety suffers preliminary de-
formation over its whole length, and then the usual " neck-
ing " takes place at the region of fracture. It is also
to be noted that the ratio of elastic limit to tensile
strength varies from 87 per cent. in the magnetic to
42 per cent. in the non-magnetic test piece.

    Steel with more than 25 per cent. of nickel present is
capable of undergoing reversible transformation, which
implies the loss of the magnetic property on heating, but
the recovery of this magnetism on cooling to the tem-
perature at which heating commenced; but this pro-
duces a much weaker degree of magnetism than does the
irreversible transformation. The maximum effect of

reversible transformation is reached with a 36 per cent. nickel steel alloy, but it is not of special interest, since it does not appreciably alter the mechanical properties, with the sole exception of the dilation. After a 36 per cent. nickel steel has undergone reversible transformation, the variation of volume with change of temperature becomes practically *nil*, rendering such an alloy of some considerable service for making self-compensating springs for watch-making, and also for motor valves. The dilation of an 18 per cent. nickel steel is very abnormal, and deserves mention. A test bar, on cooling gradually from 200° C., will contract uniformly until the temperature falls to
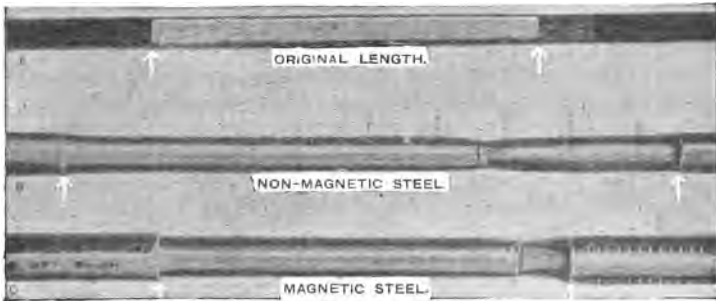
Fig. 117.—Test Pieces of 16 per cent. Nickel Steel.

130° C., and then it *expands* during the time the temperature falls to 60° C., when contraction again resumes. If now the bar be heated up to a temperature less than 130° C. (say 100° C.), it will expand normally and contract on cooling to 100° C., when it immediately expands once more until 60° C. is reached.

That nickel steel corrodes very much less than either wrought iron or mild steel is shown by Professor Howe's comparative figures obtained from specimens exposed for about one year under various conditions :—

	Weathered.	Fresh water.	Sea water.	Average.
		Immersed in		
26 per cent. nickel steel ...	30	32	32	31
3 per cent. nickel steel ...	67	80	83	77
Mild carbon steel	103	94	114	103
Wrought iron (as standard)...	100	100	100	100

Four per cent. of nickel in steel does not appear to make very much difference on the resistance of the alloy to corrosion, but with about 18 per cent. and upwards of nickel the alloy is practically incorrodible. Advantage of this is taken in the manufacture of torpedo netting in America, where an alloy of steel with ·4 per cent. carbon and almost 30 per cent. of nickel is found to combine high tensile strength with complete immunity from corrosion in the sea. The wire draws like ordinary mild steel.

Great ductility and a high limit of elasticity gives nickel steel a great value for shafting. Intermittent stress is very much more destructive than continuous, and this repetition soon causes rupture. Three to 4 per cent. of nickel present in steel increases six-fold the number of rotations such a shaft could stand, compared with an ordinary steel shaft. For armour plate, 3 to $3\frac{1}{2}$ per cent. of nickel, with ·25 per cent. of carbon, in steel combines high tensile strength with great hardness. This has brought nickel steel very largely into use as a projectile resisting material. It is deeply carburised on the impact face, and its special merit lies not so much in resistance to perforation, but that, if penetrated deeply, it does not crack or splinter. Chromium is often employed as an auxiliary in quaternary nickel steel for armour plate, the carbon ranging from ·25 to ·5 per cent., the nickel content from 2 to $3\frac{1}{2}$ per cent., and the chromium not more than 1 to $1\frac{1}{2}$ per cent. In this case the nickel seems to add toughness, whilst the carbon and chromium harden the alloy. Similar steel with low carbon (·25 to ·45 per cent.), with higher nickel content (from 5 to 6 per cent.), and a less percentage of chromium (·5 to 1 per cent.), is now in very extensive use, especially in France, for making shafts and journals fitted to motor cars. Such a steel has to be very carefully " heat treated," being much improved by air quenching—*i.e.* slow cooling from 850° C.

The use of steel with low percentages of nickel ($1\frac{1}{2}$ to 2 per cent.), containing very little carbon (·1 to ·15 per cent.), has now become general in the motor car industry, especially for axles and crank shafts, and generally where high resistance to shock is required.

Nickel steel has been employed for various other miscellaneous purposes, such as plates for high pressure

boilers to stand 500 lb. per sq. in., hydraulic cylinders, piston rods for steam hammers, ordnance and small arms (2·75 per cent. nickel with ·2 per cent. of carbon), and even tools, with 3 to 5 per cent. of nickel and ·8 per cent. of carbon.

Chromium Steel.—Chromium is added to nearly finished steel in the furnace. Ferro-chromium with about 40 per cent. of chromium is employed, and allowance is made for about 20 per cent. loss in the slag, which must be basic. For high-class tool steels it is preferable to use a refined ferro-chromium alloy, containing from 60 to 75 per cent. of chromium, made by reducing chrome iron ore in crucibles.

The effect of chromium on steel is, in general, to raise the tensile strength as the percentage of chromium increases, without at the same time diminishing the ductility seriously. Up to 1 per cent. of chromium has little or no effect, either on the tensile strength or hardness of the steel, even on quenching. In the absence of carbon, as much as 4 per cent. of chromium produces no greater hardening than the same quantity of aluminium, but with about 1 per cent. of carbon and from 2 to 3 per cent. of chromium, great stiffness with undiminished toughness is attained. Such a material is very suitable for armour-piercing projectiles, if suitably hardened and tempered to give the formation of the intensely hard double carbides of iron and chromium, suitable for penetration of armour plate.

An unannealed test bar of 5 per cent. chromium steel has registered as high a tensile strength as 72 tons per sq. in., dropping, however, to 55 tons per sq. in. on annealing the sample; the elongation ranged from 8 per cent. in the unannealed to 13 per cent. in the annealed bar. As the chromium content increases, the carbon being about 1 per cent., the alloy steel shows great hardness, increasing with further increment of chromium, until, with about 9 per cent. of chromium content, the steel can hardly be attacked by a file.

The following table and graphs of the mechanical tests carried out on a number of test pieces show the behaviour of the alloys containing varying percentages of chromium :—

Analysis.		Unannealed.				Annealed.			
Per cent.		Tons per sq. in.		Per cent.		Tons per sq. in.		Per cent.	
C.	Cr.	T. S.	E. L.	Σ.	C.	T. S.	E. L.	Σ.	C.
·07	·22	28	19½	39	64	24	16½	45	68
·15	·48	31	22½	38	44	27½	18	45	62
·14	·57	29	21	41	68	25½	15	47	69
·12	·84	31½	22	40	62	28	19	43	61
·21	1·51	38	24	37	64	33½	19	38	56
·39	2·54	54	29½	27	52	44	24½	25	34
·41	3·17	64	30	22	44	47½	21½	24	35
·77	5·19	74	40	13	20	55	20	8	7
·86	6·89	72½	40	14½	27	51	19	35	46
·71	9·18	61	30	18	28	44	18	25	37

Fig. 118.—Table of Mechanical Tests made with Chromium Steels
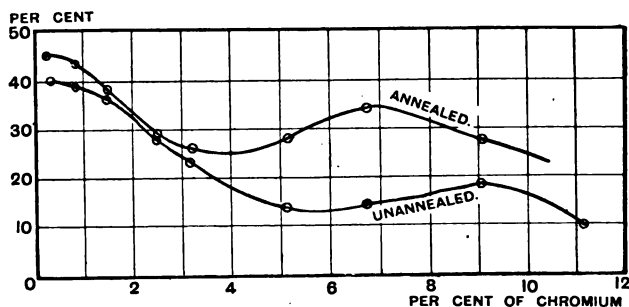
Fig. 119.—Chromium Graph Curves, showing Elongation.

Low carbon chromium steels can be forged well with up to about 12 per cent. of chromium present, but, as the carbon increases, forging makes the metal hard and brittle. This brittleness can, however, be easily removed by annealing, and the steel is rendered excessively hard by quenching in water. (Figs. 118, 119, 120, and 121.)

In addition to shells, chromium steel, with about 1·2 per cent. of carbon and 3 per cent. of chromium, is very suitable for making files. Other uses of this alloy are the manufacture of locomotive springs, tyres, and axles; dies
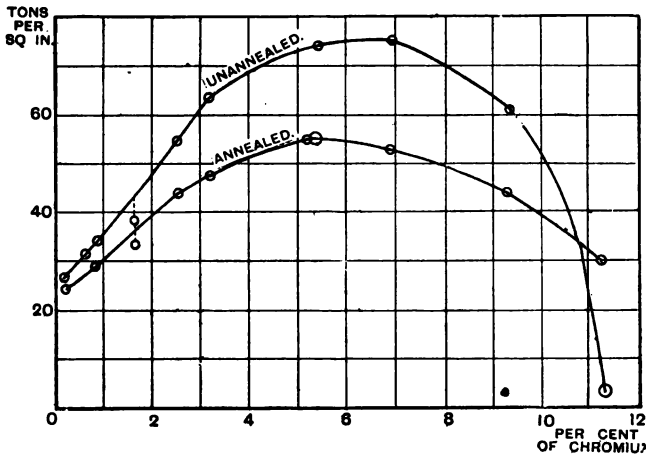
Fig. 120.—Chromium Steels—Tensile Strength.
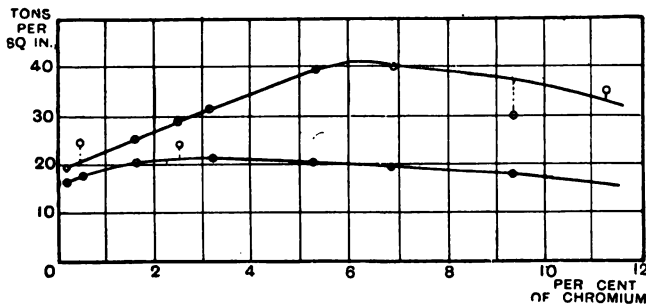
Fig. 121.—Chromium Steels—Elastic Limit.

and shoes for stamp batteries, and any tools requiring great hardness. Armour plate is frequently now made with a combined chrome-nickel steel. For safes, alternate layers of chromium steel and wrought iron are welded together and cooled suddenly. The hardness of the quenched chromium steel resists the burglar's drill, whilst the ductility of the wrought iron resists the blows of his sledge-hammer.

Under the microscope the effect of chromium on steel
is seen to be an interference with the growth of the iron
crystals, the granular structure being very minute, and
this, no doubt, accounts for the modifications which the
chromium effects on the mechanical properties of steels.
The effect is not proportional to the chromium content,
small percentages being more active than larger amounts.
At first the chromium seems to dissolve in the steel, but
as the amount increases, a double carbide of iron and
chromium is formed, which possesses great hardness.
This occurs in the steel either as isolated globules or, it
may be dissolved in the metallic matrix (on annealing at
1,200° C.), bestowing a very high degree of hardness on
the alloy.

Molybdenum Steel.—Molybdenum steel is very seldom
used as a ternary alloy, that is, one containing only one
constituent in addition to carbon in the steel, excepting
traces of the other metalloids.

Molybdenum is introduced into the steel in the form
of a ferro-molybdenum alloy, frequently prepared by the
alumino-thermic process. The general effect of from ·5
to 2 per cent. of molybdenum on steel is to slightly im-
prove the elongation and contraction tests, at the same
time giving a much higher breaking strain or tensile
strength than ordinary carbon steel. At about 3 per
cent. molybdenum content, the hardness develops sud-
denly, and whilst below this the brittleness is not more
than carbon steels, at this transition point the pearlitic
structure disappears, double carbides making their ap-
pearance, along with extreme hardness in the alloy. The
breaking strain is now very high, as is also the limit of
elasticity, with only a small percentage elongation and
contraction.

Special tool steel with molybdenum alone has now
been abandoned in favour of quaternary alloys, some con-
taining tungsten in addition to the molybdenum, but the
most popular for tools are the chromium molybdenum
alloys. The high-speed tool steels, for cutting mild steel
at rates up to 150 ft. per second, contain from 1 to 3
per cent. of molybdenum associated with from 3 to 5 per
cent. of chromium, and from 3 per cent. to as much as
8 per cent. of tungsten. This quaternary alloy is " self-

hardening," in so far that, after heating up to a temperature well above the welding point (say 1,000° C.) and cooling down slowly by a regular gradient in lime or some inert substance, great hardness is imparted to the steel. For cutting hard steel, tools of this self-hardening alloy are made by Taylor and White with 4 per cent. of molybdenum, 4 per cent. of chromium, and 5 per cent. of tungsten, which can work at a red heat without losing their cutting edge.

Tungsten Steel.—Tungsten steel is made by adding the ferro-tungsten alloy, containing about 80 per cent. of tungsten, to steel whilst in the ladle. It is, however, sometimes preferable to use crucibles for melting in the alloy for special high grade tool steel. Tungsten steel does not make sound castings, unless with the addition of a little aluminium and silicon; the fluidity of the alloy is slightly less than ordinary steel.

The general effect of the addition of tungsten to steel is to make it intensely hard; that containing about 8 per cent. of tungsten being sufficiently hard to scratch glass and even indent chromium steel, and 15 per cent. tungsten content makes the alloy too hard to machine.

From the table and graphic representations of the mechanical tests made with tungsten steel alloys given in Figs. 122 to 125, it will be noted that the tensile strength does not increase much up to 1·5 per cent. of tungsten, but above this there is a considerable rise, caused partly by the self-hardening action, the carbon also being comparatively high. On annealing test bars the tenacity is comparatively low, and even high tungsten content does not confer great tenacity. From the elastic limit results it will be seen that tungsten steel differs considerably from manganese and nickel steels, in that it does not materially raise this limit much above that of the same carbon content containing no tungsten. The annealing of tungsten steel considerably increases both the elongation and contraction, although 3·5 per cent. of tungsten gives the remarkable figure of 34 per cent. elongation and 53 per cent. reduction of area on fracture. In the higher percentages the ductility falls off rapidly.

The forging of tungsten steels presents some little
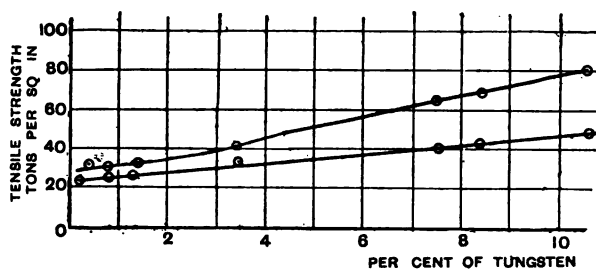
Fig. 122.—Tungsten—Tensile Strength.
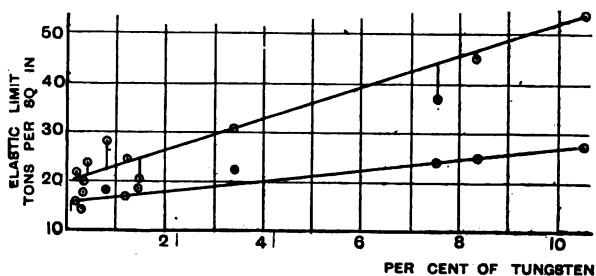
Fig. 123.—Tungsten—Elastic Limit.
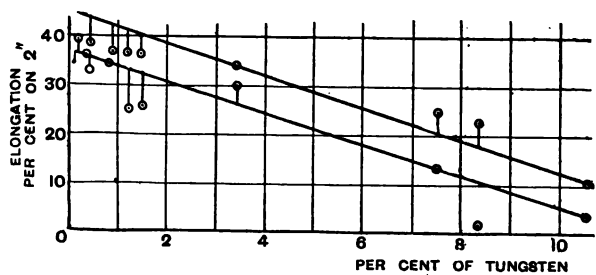
Fig. 124.—Tungsten—Elongation.

Analysis.		Unannealed.				Annealed.			
Per cent.		Tons per sq. in.		Per cent.		Tons per sq. in.		Per cent.	
C.	W.	T. S.	E. L.	Σ.	C.	T. S.	E. L.	Σ.	C.
·13	·1	25	20	35	60	22	14	43	65
·15	·2	27	22	40	60	22	16	46	66
·15	·4	31	24	33	59	25	18	39	60
·21	·81	32	29	35	63	26	18	37	53
·22	1·2	32	25	25	49	27	17	37	54
·21	1·5	34	20	26	46	28	19	37	54
·28	3·4	41	31	29	51	34	23	34	53
·38	7·47	63	37	18	24	40	24	26	38
·46	8·33	64	45	2	2	42	25	23	32
·63	10·56	80	55	5	4	48	28	10	10
·76	15·65	Too	hard	to	Machine	57	27	3	2

Fig. 125.—Table of Mechanical Tests made with Tungsten Steels.

difficulty, and, although malleable when hot, it is not nearly so malleable as ordinary carbon steel. With the percentage of tungsten below 1˙5 per cent., it does not seem to have much effect on the welding properties when the sulphur is low and manganese fairly high, yet when the reverse of this is the case, or when the tungsten exceeds 2 per cent., the welding power disappears completely.

Bending tests conducted on bars of tungsten steel show that, as cast, the increase of the percentage of tungsten gradually diminishes the toughness, especially after 3˙5 per cent. of tungsten is reached, this point being comparable with 1¼ per cent. of tungsten if the bars are annealed at about 900° C. and then water quenched, when a distinct hardening is noticeable. Unlike either the manganese or nickel steels, which, although brittle during the range of from 3 to 7 per cent. for manganese and from 10 to 15 per cent. for nickel, become tough with higher percentages, tungsten steels do not show this peculiar return of toughness, since the angle through which the bars bend decreases with the increase of tungsten.

On fracture, the tungsten steels show very marked peculiarity. First a very fine crystalline structure commences with 1˙5 per cent. of tungsten, and up to 7 per cent.

the grain is extremely close, but not silky. This characteristic appearance of silkiness only appears when the carbon content exceeds 1¼ per cent., and is seemingly, therefore, due to the presence of a carbide of tungsten in association with the carbide of iron.

Tungsten steels with a high carbon content are very retentive of magnetism, and an alloy with 5 per cent. tungsten, with ·62 per cent. carbon and ·55 per cent. manganese, is found very suitable for the manufacture of permanent magnets in electric meters. The highest magnetic power attainable with the greatest retentiveness is reached when the tungsten content is varied between 4 and 7 per cent. Low carbon steels with tungsten do not show this magnetic retentiveness.

From tests made with the heat treatment of tungsten steels, it appears that if the temperature is not raised above 800° C. the cooling curves are quite normal, but on cooling from above 1,050° C. the Ar_1 is lowered, and when from above 1,300° C. both Ar_3 and Ar_2 are lowered. With high carbon content and increasing tungsten percentages, the Ar_1 point seems to divide into two portions.

The special use of tungsten is for the production of self-hardening steels, that is, those which can be made hard enough to retain a cutting edge by heat treatment alone, without water quenching. Such steels, if plunged when red hot into water, simply crack or split. They usually contain from 5 to 8 per cent. of tungsten, with from 1·5 to 2·5 per cent. of carbon. The following are some typical analyses of special tungsten steels :—

		Analysis per cent.			
Name.	*Carbon.*	*Tungsten.*	*Manganese.*	*Silicon.*	*Chromium.*
Mushet (Osborn) ..	1·65	5·8	2 12	1·36	·45
Allevard	·42	6·22	·29	·05	—
Mushet (ordinary)...	2·0	7·81	·19	·09	—
Mushet (special) ...	2·3	8·22	1·72	1·60	—.

The first-mentioned steel is peculiar, in that it can be successfully softened for machining by heating to the temperature of incipient redness (say about 500° C.) and quenching in water.

The second-named steel, of French manufacture, can,

by quenching in water at 600° C., be rendered (*a*) very hard; (*b*) of only medium hardness; or (*c*) quite soft, according as the temperature of the preliminary heating is raised to (*a*) 1,300° C.; (*b*) 1,000° C.; or (*c*) 850° C. respectively.

The Taylor and White special "quick-speed" cutting steels, with tungsten and molybdenum or chromium, have already been mentioned. These combinations confer upon the tools made from the alloys, a temper which cannot readily be destroyed even when the rate of cutting makes the working face of the tool approach a low red heat.

Vanadium Steel.—Vanadium is alloyed with steel by the introduction of an electrically prepared ferro-compound, which may contain up to 50 per cent. of vanadium and about 1 per cent. of carbon. The sulphur in this alloy must be low (say below ·01 per cent.), otherwise the vanadium will only with difficulty be induced to enter the steel in the furnace.

Early experiments with vanadium alloys made a great impression, forecasting a valuable future for vanadium in the metallurgy of steel, the action of this comparatively rare element apparently resembling tungsten, but being nearly thirty times more powerful. Without the usual lowering of the elongation, the increase of tensile strength and elastic limit was very marked. Recent investigations indicate a classification of vanadium steels into three series, depending on the variation of the results of mechanical tests, as follows :—

First Series, in which the vanadium content increases up to 1 per cent. These steels show augmentation of tensile strength and elastic limit the greater the percentage of vanadium, with high elongation and contraction in comparison with ordinary steels of the same carbon content. The alloy steels are no more brittle than the ordinary steels, but they are possessed of greater hardness. Such alloy steels are influenced by quenching in proportion as the vanadium content rises, and they retain their high percentage of contraction.

Second Series, with the percentage of vanadium from 1 to 3 per cent. This group possesses a tensile strength and elastic limit which diminishes as the vanadium increases, the elongation and contraction both remaining

high. These alloys are not more brittle than ordinary steels, but not so hard as the steels of the first series. Quenching affects the steels of this series less and less as the vanadium percentage increases.

Third Series has a vanadium content exceeding 3 per

Analysis.		Normal.				Quenched.				Annealed.			
Per cent.		Tons per sq. in.		Per cent.		Tons per sq. in.		Per cent.		Tons per sq. in.		Per cent.	
C.	V.	T. S.	E. L.	Σ.	C.	T. S.	E. L.	Σ.	C.	T. S.	E. L.	Σ.	C.
·11	·29	28	19	24	63	34½	31	23	67	26½	18	22	58
·13	·60	31½	26	20	69	43½	26½	20	63	—	—	—	—
·14	·75	37	27½	16	58	46½	31	18	61	33	26½	13	53
·11	1·04	39	29	15	71	61	39	12	60	—	—	—	—
·13	1·54	36	28½	19	73	39	33	14	67	35	28½	16	63
·20	2·12	32	25	15	68	35	26½	12	60	—	—	—	—
·19	2·98	30	17	26	74	29	18½	21	61	—	—	—	—
·38	5·37	29½	16	17	61	28	16½	27	58	27½	15½	13	58
·13	7·34	28	16	30	63	27	16½	30	65	—	—	—	—
·12	10·27	29½	16	31	53	30	16½	22	56	—	—	—	—
·82	·25	56	28	8	20	73½	67	6	12	54½	28	6	19
·73	·60	58	30	8	22	75	70	9	20	56	30½	7	19
·89	·80	61	36	4	19	83	72½	3	10	—	—	—	—
·67	1·15	55½	37	8	26	76½	65	5	6½	53½	36	8	25
·62	1·58	60	42	9	31	72½	65	13	13	—	—	—	—
·95	2·89	58	30½	9	34	70	47	11½	18½	—	—	—	—
·67	3·06	54	37	16	29	63	43	3	6½	52½	34½	10	22
1·08	4·99	63	35	14	25	65½	37	11	41	—	—	—	—
·74	7·85	32½	18½	20	34	29	22½	27½	41	31½	18½	15	34
·89	10·25	40	20	12	38	37	27	17½	33	—	—	—	—

Fig. 126.—Table of Mechanical Tests made with Vanadium Steels.

cent., in which the whole of the carbon is present as a double carbide of iron and vanadium. They have a very low tensile strength and elastic limit, which are both practically constant with increasing percentage of vanadium. The elongation and contraction continue high, but the steels are brittle. They do not show much hardness, and the fractures show them to be extremely heterogeneous, frequently with large crystal grains near the edges. Quenching produces no change, either on the
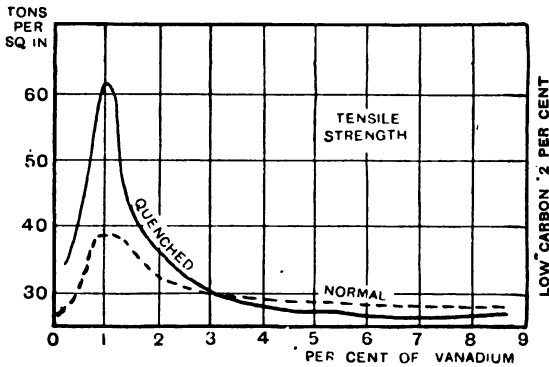
Fig. 127.—Graph of Vanadium Steel Properties—Tensile Strength.

mechanical properties or microstructure of this group of vanadium steels. The following tables contain the effects of change of vanadium content on the microstructure and mechanical tests (Figs. 126, 127, 128, 129, and 130).

Series.	Microstructure.	Low carbon content and vanadium per cent. of	High carbon content and vanadium per cent. of
I.	Pearlite...	0 to ·7	0 to ·5
II.	Pearlite and double carbide	·7 to 3·0	·5 to 7·0
III.	Double iron and vanadium carbide	over 3·0	over 7·0
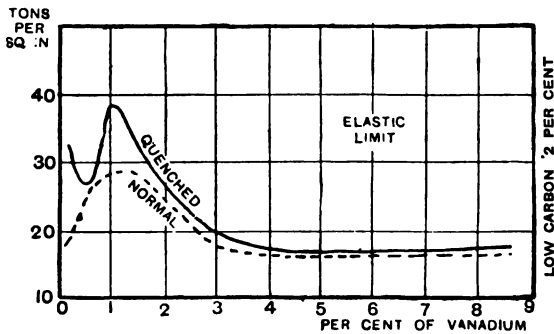
Fig. 128.—Graph of Vanadium Steel Properties—Elastic Limit.

All vanadium steels become softened on annealing, although this influence is not very pronounced in normal steels. If the heating were prolonged sufficiently to produce the separation of the carbon as graphite, then the steels would evince extreme brittleness. Vanadium steels are peculiarly sensitive to the influence of work, subsequent to which it is absolutely necessary to anneal them by heating to 900° C. and gradually recooling (See the graph, Fig. 127.)

The only vanadium steels of commercial importance are those containing less than ·7 per cent. of vanadium, for which class a good industrial future is assured if satisfactory ferro-vanadium can be produced cheaply enough. Since the most valuable vanadium steels only contain from ·2 to ·5 per cent. of this element, the cost should not be prohibitive, and these steels should prove invaluable in cases where high resistance to shock, coupled with great resistance to alternating stress, is required.

The bulk of the vanadium open-hearth steel now produced is absorbed by the automobile industry, where the demand is rapidly increasing, but wider fields of usefulness are open to vanadium steels, since it not only welds excellently, and is practically self-lubricating in bearings, but also exhibits an extraordinarily high resistance to torsion. Thus a $\frac{3}{4}$-in. circular test bar has been known to withstand a torsional shearing strain of 40 tons per sq. in., the final twist angle being nearly four complete turns (approximately 1,400 degrees).

The quaternary vanadium steels are very complex, and only interesting from the fact that the tensile strength and elastic limit (as in the case of vanadium manganese and vadium nickel steels) are raised, more especially in the pearlitic steels.

Aluminium Steel.—Aluminium is always added to the steel produced in " wild heats " to save it from boiling out of the moulds. Only a very small quantity is needed, and practically none of it is left in the ingot unless a considerable quantity of metallic aluminium is added during the teeming. Two ounces of aluminium added to each ton of steel in the ladle produces increased fluidity, possibly due to the removal of the oxygen from dissolved Fe_3O_4, but it is certainly not due to such addition lower-
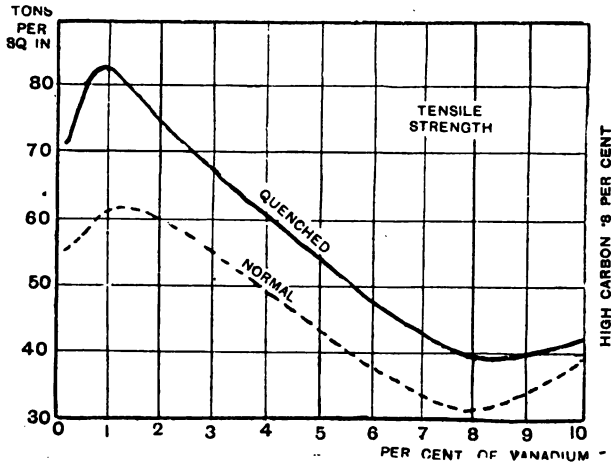
Fig. 129.—Graph of Vanadium Steel Properties.—(Tensile Strength).
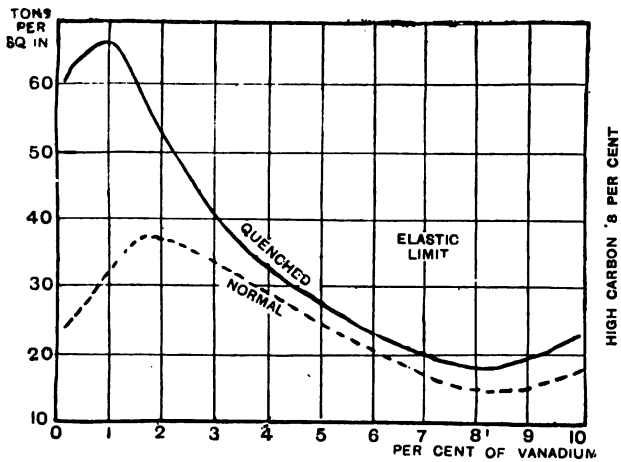
Fig. 130.—Graph of Elasticity of Vanadium Steel.

P

ing the melting point. When the percentage of aluminium present exceeds ·5 per cent., the metal becomes " creamy " in pouring and sets quickly but soundly.

The addition of aluminium does not much affect the hardness of steel, and water quenching seems to produce no effect in the absence of carbon. In presence of carbon, however, aluminium does not retard the hardening effect of quenching. Aluminium renders cast steel coarsely

Analysis.		Unannealed.				Annealed.			
Per cent		Tons per sq. in.		Per cent.		Tons per sq. in.		Per cent.	
C.	Al.	T. S.	E. L.	Σ.	C.	T. S.	E. L.	Σ.	C.
·22	·15	29	21	37	63	25	20	42	64
·15	·38	30	23	38	58	26	20	40½	60¼
·2	·61	28	21½	38½	54½	25½	18	40½	62
·18	·66	29	20½	33½	50	27	18	33	52
·17	·72	28	22	40	61	25	18	47	65
·26	1·16	33	23	32	51½	29	21	34½	53
·21	1·60	31	20	33	52	26	13	36½	67
·21	2·2	31	21	23	28	28	19	35	47
·24	2·24	32½	21½	20½	24½	28½	18½	33	48½
·22	5·6	38	none visible	4	4	36	27	6½	6

Fig. 131.—Table of Mechanical Tests made with Aluminium Steels.

crystalline, and, on exceeding 5 per cent., produces cleavage faces like spiegeleisen, yet up to 5 per cent. of aluminium added to spiegel reduces the size of the carbon plates on fracture to a grade similar to a No. 3 pig iron.

The toughness of steel is perceptibly diminished as the aluminium percentage exceeds ·85 per cent., although annealed bars with up to 2 per cent. of aluminium can be bent double in the cold. The malleability of the steel practically vanishes as the aluminium rises above 6 per cent., and the welding of steels comparatively low in aluminium is effected only with difficulty. (Figs. 131 and 132.)

From the above table of mechanical tests it will be noted that, whilst the elastic limit rises slightly with

increased percentages of aluminium, the tensile strength
varies considerably, but increases appreciably with 5 per
cent. of aluminium present. The improvement shows 11
tons per sq. in. on annealed as compared with about
9 tons on unannealed bars. At the same time, the elonga-
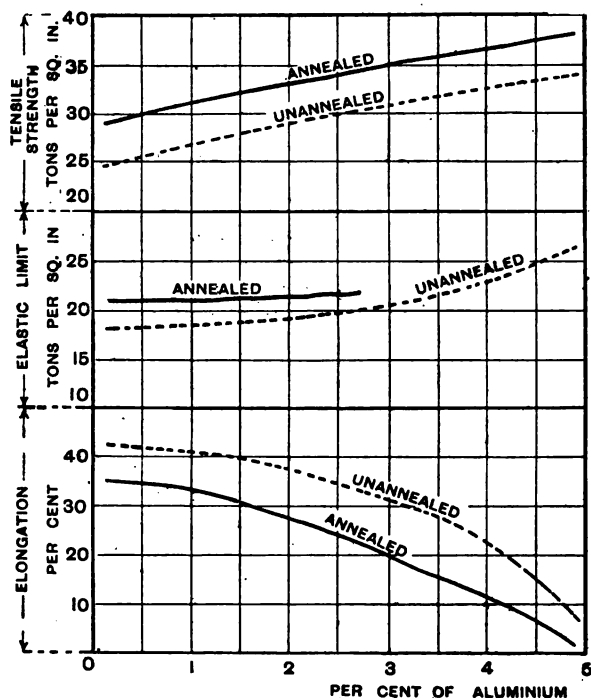
Fig. 132.—Graphs of Aluminium Steel Properties.

tion and reduction of area fall off very rapidly with
5 per cent. aluminium, this effect being augmented as the
carbon content increases.

As the percentage of aluminium increases from 5 to
10 per cent., the specific gravity of the alloy steel falls most
remarkably, viz. from 7.5 to 6.6; and whilst an ingot of

steel with 5 per cent. aluminium present is inclined to be rather "shelly" in forging, when 10 per cent. content is reached forging is quite impossible.

Aluminium, in producing but little stiffening effect on steel, acts in general very similarly to silicon, only less powerfully; for example, the increase in tensile strength and elastic limit is not so great. The main use of aluminium lies in producing soundness, more especially in very mild steels, where silicon is not so serviceable. Manganese and silicon together seem to have much the same effect as aluminium in some respects, and, these elements being chiefly combined in spiegeleisen, aluminium is not likely to be used very extensively.

Silioon Steel.—Silicon steel can be made either by adding silicon iron to the metal in the furnace or ferrosilicon to the ladle before tapping, but for high silicon content it is necessary to add it to the steel melted in crucibles. On casting, the fluidity is noticeably less than ordinary steel, and, although it casts well and free from pipes or honeycombs, this soundness is acquired at the expense of toughness or ductility and great shrinkage in the moulds.

The fracture, with low silicon content, is quite silky until above 2·5 per cent. is present, when the crystal grains become enlarged and glazed, like spiegeleisen. With increased silicon the metal is exceedingly brittle, resembles silicon pig iron in fracture, and is quite unmalleable with over 6 per cent. of silicon in a low carbon steel. The malleability is not much impaired with less than 6 per cent. of silicon, unless the carbon content is increased.

The tensile strength and elastic limit both increase, without loss of ductility, with silicon additions up to 1½ per cent., but after that, further raising of the strength by increasing the silicon is only obtained with serious loss of ductility, as shown by the table of mechanical tests. (Fig. 133.)

Water quenching produces no hardening whatever on steels with up to 2 per cent. of silicon, even if plunged at welding heat (1550° C.) into ice-cold water. With higher percentages the quenching only stiffens the metal without diminishing the brittleness or increasing the hardness. Under compression, a sample containing 2·7 per

cent. of silicon crushed up 38 per cent. of its length under a load of 100 tons per sq. in., a figure not exceeded even by a mild steel of ·2 per cent. carbon content, so that silicon is not nearly so powerful a hardener of steel as carbon.

Silicon steels are now largely used in motor car construction, the alloy most frequently employed containing from ·8 to ·9 per cent. of silicon, with about ·7 per cent.

Analysis.		*Unannealed.*				*Annealed.*			
Per cent.		*Tons per sq. in.*		*Per cent.*		*Tons per sq. in.*		*Per cent.*	
C.	*Si.*	*T. S.*	*E. L.*	*Σ.*	*C.*	*T. S.*	*E. L.*	*Σ.*	*C.*
·14	·24	33	22	30	54	25	15	37	61
·18	·73	34	25	29½	54¼	29¼	19	34	52¼
·19	1·6	37¼	28	31	50	33	25	35	54¼
·20	2·18	39¼	31	18¼	28	34	25¼	36¼	60
·20	2·7	42¼	32	17¼	24	32	24	6	6¼
·21	3·4	47¼	35	11	14	39	30	9	9
·25	4·2	49	45	·004	·2	38	none visible	·64	·98
·26	5·5	48	none visible	·3	·7	25	25	·37	·5

Fig. 133.—Table of Mechanical Tests made with Silicon Steels.

of carbon and 4 per cent. manganese. These have to be very carefully heat-treated, in order to obtain the proper mechanical properties. Tests made with this steel give, on varying treatment, the following results :—

	Tons per sq. in.		*Per cent.*
	T S	*E L*	*E*
Annealed at 900° C.	48 to 54	29 to 32	14 to 18
Quenched at 900° C.	95	95	0 to 2
Quenched and reheated to 500° C. ...	85 to 95	63 to 67	5 to 12

The weak point in silicon steels is their extreme brittleness at right angles to the plane of rolling. The surface hardness of gear wheels can, by suitable treatment, be made very great, thereby preventing the metal from spreading, but the principal use of silicon steel at present is for the manufacture of springs in motor cars.

Steels of Less Importance.—Cobalt steel is easily made by the addition of metallic cobalt to steel, but even up to 30 per cent. of cobalt produces very little influence on the mechanical tests. The only change is a slight increase in the tensile strength, but not sufficient to make any of the cobalt steels of industrial importance. They all belong to the pearlitic series, at least with up to 30 per cent. of cobalt and not more than ·8 per cent. of carbon.

Tin steel is made by the solution of the metal in ordinary steel. Up to 5 per cent. readily dissolves to form a stannide of iron, and the carbide, with up to 10 per cent. of tin present, always remains pearlitic. Steel with 1·5 per cent. of tin is very difficult to forge, and more than 2 per cent. makes it unworkable. This steel is excessively brittle, crumbling to powder on dropping a few feet on to a hard floor. Although 5 per cent. of tin makes steel very hard, there is practically no use for any member of this set of alloy steels.

Titanium is very difficult to introduce into steel, the only way being by the use of an electrically-prepared ferro-titanium alloy. It is not that its solution in the steel is difficult to accomplish, but that great care has to be taken to prevent the oxidation, not only of part, but sometimes even of the whole of the titanium present. In fact, many steels sold under the name of titanium steels are completely devoid of that element.

More than 10 per cent. of titanium is almost impossible to get into combination with steel, on account of the furnace temperatures available not being sufficient to fuse higher alloys. Tests made with specimens prepared did show a certain degree of improvement in the strength and hardness, but disappointingly small in comparison with ordinary steels of similar carbon content. The low resistance to shock obtained also showed these steels to be almost totally devoid of industrial importance.

Commercially, the only possibility of the use of titanium is the extreme readiness with which it absorbs oxygen, so that as a purifying agent it might replace silicon or aluminium.

Fig. 134 is a comparative table of the mechanical tests made with varying content alloy steels, which is only approximate on account of fractions being neglected.

Alloy steel containing	Analysis. Per cent.		Unannealed. Tons per sq. in.		Per cent.		Annealed. Tons per sq. in.		Per cent.	
	Alloy.	C.	T. S.	E. L.	Σ.	C.	T. S.	E. L.	Σ.	C.
Nickel	·27	·19	31	19	35	36	28	20	37	52
Chromium . . .	·29	·16	28	21	42	67	25	17	46	66
Tungsten . . .	·20	·15	27	22	40	60	22	16	46	66
Vanadium . . .	·29	·11	28	19	24	63	26	18	22	58
Aluminium . .	·38	·15	30	23	38	58	26	20	40	60
Silicon	·24	·14	33	22	30	54	25	15	37	61
Nickel	·95	·13	33	25	31	53	27	20	41	63
Chromium . . .	·84	·12	31	22	40	62	28	19	43	61
Tungsten . . .	·81	·21	32	29	35	63	26	18	37	53
Vanadium . . .	·75	·14	37	27	16	58	33	26	13	53
Aluminium . .	·66	·18	29	20	33	50	27	18	33	52
Silicon	·73	·18	34	25	29	54	29	19	34	52
Nickel	1·92	·14	34	26	33	55	31	22	36	53
Chromium . . .	1·51	·21	38	24	37	64	33	19	38	56
Tungsten . . .	1·49	·21	34	20	26	46	28	19	37	54
Vanadium . . .	1·54	·13	36	28	19	73	35	23	16	63
Aluminium . .	1·60	·21	31	20	33	52	26	13	36	67
Silicon	1·60	·19	37	28	31	50	33	25	35	54
Nickel	3·82	·19	37	28	30	54	33	25	35	55
Chromium . . .	2·54	·39	54	29	27	52	44	24	25	34
Tungsten . . .	3·40	·28	41	31	29	51	34	23	34	53
Vanadium . . .	2·98	·19	30	17	26	74	28	17	15	60
Aluminium . .	2·24	·24	32	21	20	24	28	18	33	48
Silicon	2·18	·20	39	31	18	28	34	25	36	60
Nickel	5·81	·18	41	28	27	40	37	28	33	51
Chromium * . .	5·19	·77	74	40	13	20	55	20	8	7
Tungsten . . .	7·47	·38	63	37	18	24	40	24	26	38
Vanadium . . .	5·37	·38	29	16	17	61	27	15	13	58
Aluminium . .	5·60	·22	38	none visible	4	4	36	27	6	6
Silicon	5·50	·26	48	none visible	0·3	0·7	25	25	0·4	0·5

* Carbon content too high to make true comparison.

Fig. 134.—Table of Comparative Mechanical Tests made with Various Alloy Steels.

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